

AD-A128 805

A PROGRAM TO COMPUTE VERTICAL ELECTRIC ELF FIELDS IN A  
LATERALLY INHOMOGE... (U) NAVAL OCEAN SYSTEMS CENTER SAN  
DIEGO CA J A FERGUSON ET AL. 01 DEC 82 NOSC/TR-851

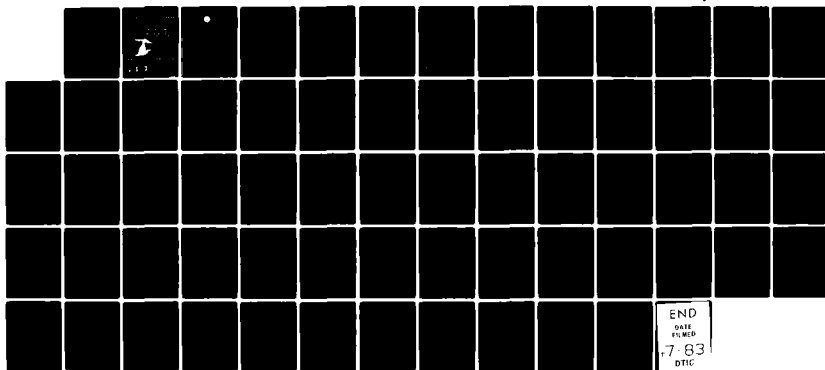
1/1

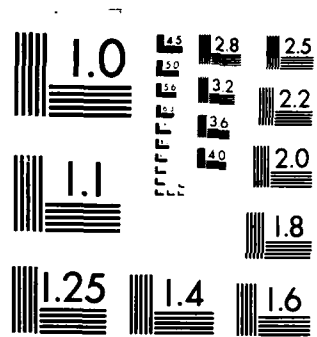
UNCLASSIFIED

DNA-MIPR-82-608

F/G 20/14

NL





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

12

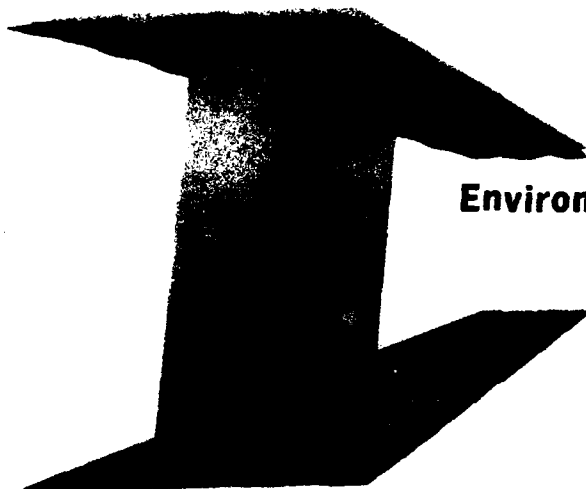
NOSC TR 851

NOSC TR 851

ADA 128805

## Technical Report 851

# A PROGRAM TO COMPUTE VERTICAL ELECTRIC ELF FIELDS IN A Laterally Inhomogeneous Earth-Ionosphere Waveguide



JA Ferguson  
LR Hitney  
and

RA Pappert  
Environmental Sciences Department

1 December 1982

Prepared for  
Defense Nuclear Agency

Approved for public release; distribution unlimited

DTIC FILE COPY

DTIC  
ELECTE  
JUN 1 1983  
S D  
B

# NOSC

NAVAL OCEAN SYSTEMS CENTER  
San Diego, California 92152

88 06 01 084



NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92162

---

**AN ACTIVITY OF THE NAVAL MATERIAL COMMAND**

**JM PATTON, CAPT, USN**

**Commander**

**HL BLOOD**

**Technical Director**

**ADMINISTRATIVE INFORMATION**

This work was performed under program element 62715H, project 99QAXHB (NOSC 532-MP20) by members of the Propagation Modeling Branch and was accomplished from June 1982 to December 1982. This document was approved for publication 1 December 1982.

Released by  
JH Richter, Head  
EM Propagation Division

Under authority of  
JD Hightower, Head  
Environmental Sciences Department

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NOSC Technical Report 851 (TR 851)	2. GOVT ACCESSION NO. AD-P128805	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A PROGRAM TO COMPUTE VERTICAL ELECTRIC ELF FIELDS IN A Laterally INHOMOGENEOUS EARTH-IONOSPHERE WAVEGUIDE		5. TYPE OF REPORT & PERIOD COVERED Interim June 1982 - December 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) JA Ferguson LR Hitney and RA Pappert		8. CONTRACT OR GRANT NUMBER(s) DNA MIPR 82-608
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Systems Center San Diego, CA 92152		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62715H, 99QAXHB (NOSC 532-MP20)
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Nuclear Agency Washington, DC 20305		12. REPORT DATE 1 December 1982
		13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  ELF radio; D-region, Sporadic-E Numerical predictions		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  A computer program for calculating ELF propagation in a laterally nonuniform earth ionosphere waveguide is presented. The program is based on a simple surface propagation model formulated in terms of an integral equation which is solved using a moment method. The disturbance must be localized to the extent that the waveguide disturbance must effectively vanish outside a rectangle of several megameters on a side. The program allows for modeling rectangular, circular, and elliptical disturbances. The lateral propagation function for the vertical electric dipole is calculated. Waveguide height effects are allowed for within the spirit of the WKB approximation. The total vertical electric field is also calculated.		

DD FORM 1 JAN 73 1473

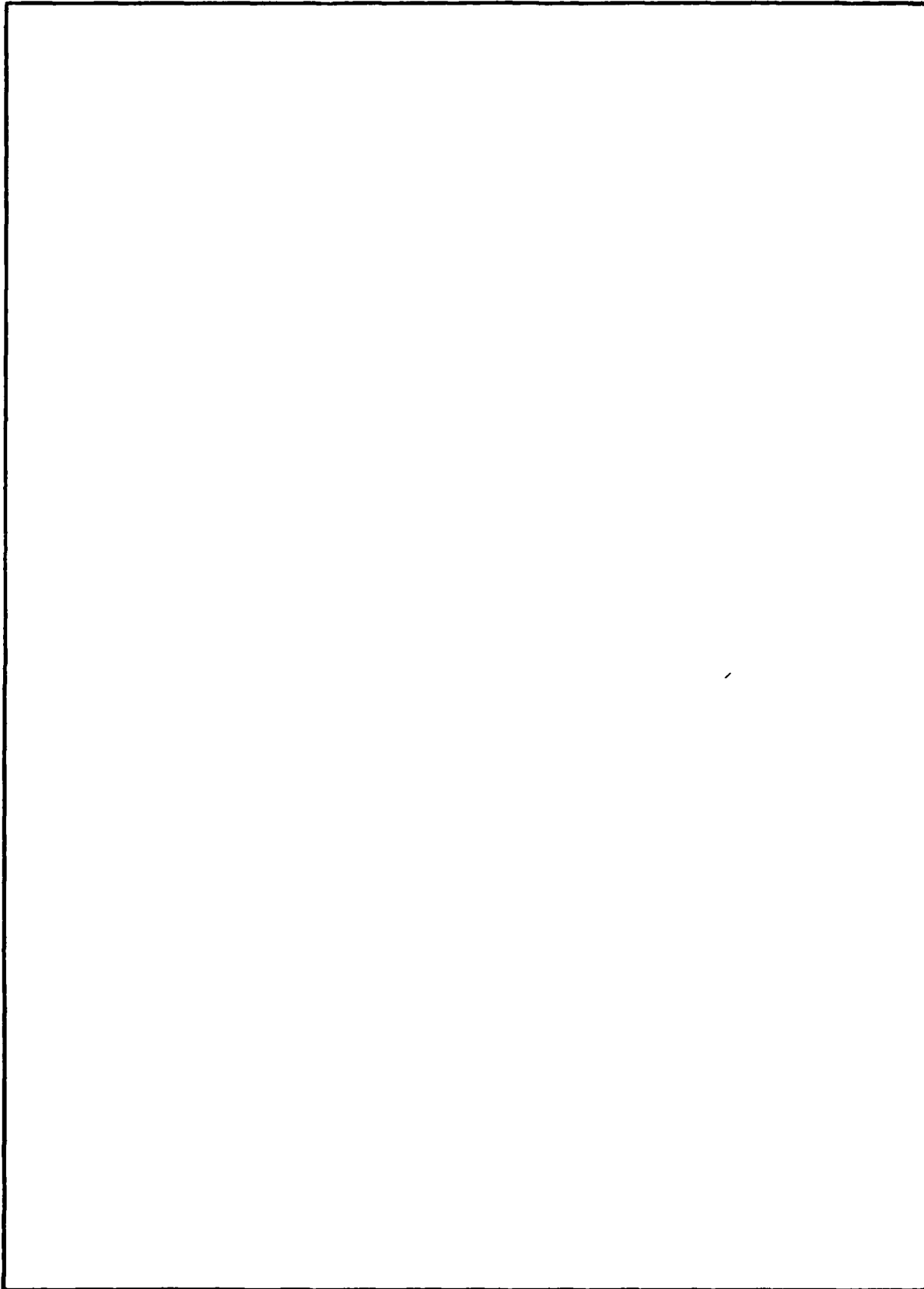
EDITION OF 1 NOV 65 IS OBSOLETE  
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



S/N 0102- LF- 014- 6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## CONTENTS

I	INTRODUCTION . . .	page 3
II	SUMMARY OF EQUATIONS . . .	5
III	GEOMETRICAL MODELING OF THE DISTURBANCE . . .	10
IV	DESCRIPTION OF INPUT . . .	13
V	DESCRIPTION OF OUTPUT . . .	17
VI	PROGRAM CHECKS . . .	26
VII	REFERENCES . . .	34
VIII	APPENDIX: PROGRAM LISTING . . .	37

## ILLUSTRATIONS

1. Diagram illustrating the distribution of S within a rectangular disturbance. The similarly shaded regions have the same value of S . . . page 11
2. Sample data input for the computer program . . . 14
3. Sample printed output generated by the first case called out in the sample data . . . 18-21
4. Sample x-variation plot for WMAG assuming a rectangular disturbance . . . 22
5. Sample x-variation plot for EZUMAG and EZPMAG assuming a rectangular disturbance . . . 23
6. Sample y-variation plot for WMAG assuming a rectangular disturbance . . . 24

7. Sample y-variation plot for EZUMAG and EZPMAG assuming a rectangular disturbance...25
8. Comparision between analytic solution and the computer program output for problem 1: a uniform circular disturbance...28
9. Comparision between analytic solution and the computer program output for problem 2: a uniform circular disturbance to  $r_0$  with an inverse  $r^2$  dependence of  $S_p$  between  $r_0$  and  $r_1$  using a 10 x 10 mesh...32
10. Comparision between analytic solution and the computer program output for problem 3: a uniform circular disturbance to  $r_0$  with an inverse  $r^2$  dependence of  $S_p$  between  $r_0$  and  $r_1$  using a 17 x 17 mesh...33

# TABLE

1. Namelist variables and initial values ... 16



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

## I. INTRODUCTION

Since an ELF signal from a remote transmitter is received over a range of azimuth angles, lateral ionospheric gradients produced by sporadic E layering or nuclear depressions can produce significant effects on propagation in the lower ELF band. This is because the Fresnel zone size can be large as compared with the distance over which the ionosphere changes significantly in the lateral direction. Although a number of workers have addressed the question of off-path effects (Wait<sup>1</sup>, Galejs<sup>2</sup>, Greifinger and Greifinger<sup>3</sup>, Field<sup>4,5</sup>, Field and Joiner<sup>6,7</sup>, Pappert<sup>8</sup>) no formulation exists which can fully account for the propagation effects produced by a localized disturbance with simultaneous allowance for vertical inhomogeneity, lateral inhomogeneity, and anisotropy in a spherical geometry. It has been common practice to estimate the effects of lateral gradients by using a simple surface propagation model introduced by Wait and more fully developed by the Greifingers and Field. The formulation reduces the problem to an integral equation description of propagation along the earth's surface. The theory is predicated on the palatable assumption that the field can be separated into lateral and height dependent functions when the lateral ionospheric gradients are considerably smaller than the vertical gradients. When applying the method to nocturnal environments additional assumptions are made. Among these is the omission of nonreciprocal effects. This is well justified in the ambient case<sup>9</sup> as well as for daytime and depressed ionospheres. However, it is known that under sporadic E layering considerable mixing between TE and TM wave can occur<sup>10</sup>. Thus, when the surface propagation model is applied to sporadic E environments the scattered TE component is neglected. The validity conditions

for the formulation are probably best satisfied under conditions of either natural or man-made depressed ionospheres.

The purpose of this report is to document a computer program, based on the surface propagation model, which is useful to the user community for estimating the effects of localized ionospheric disturbances on propagation of the vertical electric field component  $E_z$  at lower ELF frequencies. A moments method<sup>11</sup> serves as the basis for the solution of the integral equation. Though the method is powerful, in the present program, practical storage requirements restrict application to disturbances which effectively vanish outside a rectangle of several megameters on one side. It is hoped that limitation will be relaxed in future work. The program allows in some measure, for modeling of rectangular, circular, and elliptical disturbance shapes. The lateral propagation function,  $W$ , defined as the ratio of the disturbed laterally dependent part of the vertical field component,  $E_z$ , to the undisturbed field component is calculated as is the absolute value of the total  $E_z$  field component in the disturbed guide. The latter calculation allows in approximate manner for guide height effects via WKB formalism as applied to waveguide propagation.

The program requires eigenangle inputs for both the ambient and disturbed regions of the guide as well as end-on horizontal dipole excitation factors for the vertical  $E_z$  field component. These must be supplied from a waveguide program such as that of reference 12.

## II. SUMMARY OF EQUATIONS

Subject to the assumption that the vertical,  $E_z$ , field component can be separated into lateral and height dependent functions, the lateral dependence  $\psi(x,y)$  is given by<sup>5</sup>

$$\psi(x,y) = \psi^i(x,y) - \frac{ik^2}{4} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} dx' dy' (S^2(x',y') - S_0^2) G(|\vec{r} - \vec{r}'|) \psi(x',y') \quad (1)$$

where  $S$  is the sine of the eigenangle for the disturbed guide,  $S_0$  the sine for the unperturbed guide,  $k$  the free space wave number, and the superscript  $i$  signifies the unperturbed incident field. The Green's function  $G(|\vec{r} - \vec{r}'|)$  is given by

$$G(|\vec{r} - \vec{r}'|) = \sqrt{\frac{|\vec{r} - \vec{r}'|}{a_e \sin\left(\frac{|\vec{r} - \vec{r}'|}{a_e}\right)}} H_0^{(2)}\{kS_0|\vec{r} - \vec{r}'|\} \quad (2)$$

where

$$\vec{r} = x\vec{i} + y\vec{j} \quad \text{and} \quad \vec{r}' = x'\vec{i} + y'\vec{j}. \quad (3)$$

Here  $a_e$  is the earth's radius and the  $x, y, z$  are the Cartesian coordinates.  $z$  is measured vertically upwards into the ionosphere and  $x$  is measured horizontally with  $x-z$  the plane of incidence. Unit vectors in the  $x$  and  $y$  directions are denoted by  $\vec{i}$  and  $\vec{j}$ . The square root factor in equation (2) has been introduced to allow for the geometric spreading appropriate to a spherical geometry. Beyond that,  $x, y$  and  $x', y'$  are taken to be rectangular coordinates in a flat earth geometry. The quantity  $H_p^{(2)}$  is the Hankel

coordinates in a flat earth geometry. The quantity  $H_p^{(2)}$  is the Hankel function of order  $p$  of the second kind. The unperturbed lateral dependent function,  $\psi^i$ , is taken to be appropriate for the vertical electric field,  $E_z$ , launched by the end-on component of a ground based horizontal electric dipole source oriented in the  $x$  direction and given by

$$\psi^i = B \sqrt{\frac{|\vec{r}|}{a_e \sin(\frac{|\vec{r}|}{a_e})}} H_1^{(2)}\{kS_0 |\vec{r}|\} \frac{x}{|\vec{r}|} \quad (4)$$

where  $B$  is a constant. Again the square root factor allows for the spreading appropriate to a spherical geometry. The discrete analog of equation (1) for field points within the disturbed region consists of the  $N \times N$  system of linear equations:

$$\sum_{n=1}^N A_{mn} \psi_n = \psi_m^i ; m = 1, 2, \dots, N \quad (5)$$

Allowance is made for modeling rectangular, circular, and elliptical disturbances by subdividing them into square mesh cells. It is common practice in such circumstances to simplify the integrations involving cylindrical functions by approximating each square cell by a circle of equal area. It is also common practice to take the electric field to be constant over the area of a cell. However, larger cells can be tolerated if the electric field is allowed to vary over the area of a cell. At least two methods of allowing for this variation have been described in the literature<sup>13</sup>. In this work the method called 'plane wave correction' is used. The method assumes isotropic propagation within and between each cell and that should be a reasonable approximation in the present problem since anisotropy of propagation at ELF

frequencies is quite small. Translated into the notation of this work, the results of reference 13 yield for the A-matrix elements:

$$A_{mm} = 1 + \left( \frac{S_m^2}{S_0^2} - 1 \right) \left[ \left( \frac{S_m^2}{S_0^2} + 1 \right) + \frac{i\pi}{2} kS_0 a \left( 1 - \frac{1}{4} (kS_m a)^2 \right) H_1^{(2)}(kS_0 a) + \frac{i\pi}{4} (kS_m a)^2 H_2^{(2)}(kS_0 a) \right] \quad (6)$$

$$A_{mn} = \frac{i\pi kS_0 a}{2} \left( \frac{S_n^2}{S_0^2} - 1 \right) G(|\vec{r}_m - \vec{r}_n|) \left[ \left( 1 - \frac{1}{4} (kS_n a)^2 \right) J_1(kS_0 a) + \frac{1}{2} \left( \frac{S_n^2}{S_0^2} \right) kS_0 a J_2(kS_0 a) \right] ; m \neq n \quad (7)$$

The Green's function,  $G$ , is given by equation (2) with  $\vec{r}_m$  replacing  $\vec{r}$  and  $\vec{r}_n$  replacing  $\vec{r}'$ . Also,  $J_p$  is the Bessel function of order  $p$  of the first kind. In terms of the  $\psi_n$  determined by equation (5), and the  $A_{mn}$  given by equation (7), the field at a point,  $\vec{r}_m$ , exterior to the disturbed region is given by:

$$\psi(\vec{r}_m) = \psi^i(\vec{r}_m) - \sum_{n=1}^N A_{mn} \psi_n \quad (8)$$

Equations (5) through (8) are used in the present program to determine the dB value,

$$W = 20 \log_{10} \{ \psi(x, y) / \psi^i(x, y) \}, \quad (9)$$

of the disturbed lateral function relative to its undisturbed value.

Another output of the program makes allowance for dependence of the vertical electric field on height of the guide via the approximate WKB formalism. For a laterally homogeneous guide the  $E_z$  field generated by the end-on component of a horizontal dipole may be expressed as

$$E_z \sim -iQ \frac{S^{3/2}}{\frac{\partial F}{\partial \theta}} \frac{(1 - R_{\perp\perp} \bar{R}_{\perp})}{\bar{R}_{\parallel}} (1 + \bar{R}_{\parallel}) \{C(1 - \bar{R}_{\parallel})\} \Psi(x, y) \quad (10)$$

where  $F$  is the modal function and  $\partial F / \partial \theta$  its derivative evaluated at the eigenangle.  $S$  and  $C$  are the sine and cosine of the eigenangle.  $\bar{R}_{\perp}$  and  $\bar{R}_{\parallel}$  are TE and TM Fresnel reflection coefficients referenced to the ground and  $R_{\perp}$  is the ionospheric TE reflection coefficient referenced to the ground. In the absence of anisotropy the quantity  $(1 - R_{\perp\perp} \bar{R}_{\perp})$  would cancel an identical term occurring in the  $(\partial F / \partial \theta)$ . The Fresnel coefficient  $\bar{R}_{\parallel}$  is

$$\bar{R}_{\parallel} = (N_G^2 C - \sqrt{N_G^2 - S^2}) / (N_G^2 C + \sqrt{N_G^2 - S^2}) \quad (11)$$

where  $N_G$  is the complex refractive index of the ground. Because the magnitude of  $N_G$  is much greater than unity in the lower ELF band good approximations are:

$$1 + \bar{R}_{\parallel} \approx 2 \quad \text{and} \quad C(1 - \bar{R}_{\parallel}) \approx 2/N_G \quad (12)$$

Thus, within the spirit of the WKB approximation the  $E_z$  field becomes

$$E_z \approx -4Qi \left[ \frac{S^{3/2}}{\frac{\partial F}{\partial \theta}} (1 - R_{11} \bar{R}_1) \right]_r^{1/2} \left[ \frac{S^{3/2}}{\frac{\partial F}{\partial \theta}} (1 - R_{11} \bar{R}_1) \right]_t^{1/2} \frac{1}{N_G t} \psi(x, y) \quad (13)$$

where  $Q$  is a constant dependent upon dipole moment and frequency and the subscripts  $r$  and  $t$  stand for receiver and transmitter. That is, the first term in parenthesis is evaluated at the receiver while the second term in parenthesis and the factor  $N_G^{-1}$  are evaluated at the transmitter.

The factor  $B$  in equation (4) is taken to be

$$B = \sqrt{\frac{\pi k S_0 a}{2}} e^{-(3/4)\pi i} \quad (14)$$

To express the vertical electric field,  $E_z$ , as given by equation (13) in microvolts/m, the factor  $Q$  has the value

$$Q = 2.849 \times 10^{-3} f_{\text{kHz}}^{3/2} (Idl) \quad (15)$$

where  $f_{\text{kHz}}$  is the frequency in kHz and  $Idl$  is the current moment in ampere meters.

### III. GEOMETRICAL MODELING OF THE DISTURBANCE

As described in the introduction, the program can be used to model square, rectangular, circular, and elliptical disturbances. In all cases the disturbance is defined to be symmetrical about both its  $x$  and  $y$  axes. The special case of a rectangular disturbance is required to be uniformly disturbed. Let  $x_0$  and  $y_0$  denote the coordinates of the center of the disturbance with respect to the location of the transmitter. Let  $L_x$  and  $L_y$  be the size of the disturbance along the  $x$  and  $y$  axis. The disturbance is overlaid by a grid which has  $n_x$  squares along the  $x$  axis and  $n_y$  squares along the  $y$  axis. The choice of  $L_x$ ,  $L_y$ ,  $n_x$ , and  $n_y$  must be such that  $L_x/n_x = L_y/n_y$ .

Since we assume that the disturbance is symmetrical about the  $x$  and  $y$  axis, we only need to specify the waveguide eigen solution parameters along the  $x$  axis. Let us denote these solutions by  $S_i$ . We take  $i = 0$  to denote the ambient or undisturbed values. The remaining  $S_i$  ( $S_1$  through  $S_N$ ) is assumed to be uniformly distributed along the  $x$  axis from  $x_0$  to  $x_0 + \frac{1}{2} L_x$ . Note that the value of  $n_x$  is not related to that of  $N$ . If  $N = 1$ , then a uniform disturbance will be assumed. This is required for the rectangular disturbance. The remaining problem is to fill the disturbance grid with interpolated values of  $S$ .

Let us now consider a single subsquare within a square disturbance. Let the coordinates of the center of this subsquare be  $x$  and  $y$ . The smaller value of  $|x - x_0|$  and  $|y - y_0|$  is used to interpolate a value of  $S$  from the input list of  $S_i$ . This results in the disturbance grid being filled as illustrated in figure 1. In the figure the similarly shaded regions would all have the same value of  $S$ .

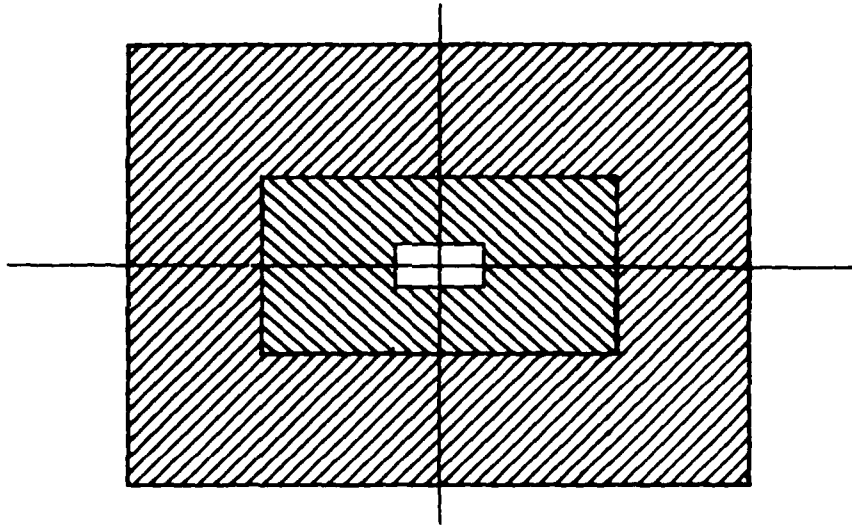


Figure 1. Diagram illustrating the distribution of S within a rectangular disturbance. The similarly shaded regions have the same value of S.

Let us consider an elliptical disturbance with an axial ratio  $R = L_y/L_x$ . The center of a given subsquare is at  $x$  and  $y$ . We can define an ellipse which is concentric with that of the outer edge of the disturbance. This ellipse intersects the  $x$  axis at a distance from  $x_0$  defined by

$$A = \{ (x-x_0)^2 + [(y-y_0)/R]^2 \}^{1/2} \quad (16)$$

The above expression can be used to calculate the value of  $A$  for each corner of the subsquare, say  $A_i$  where  $i = 1, 2, 3$  or  $4$ . If the smallest of the  $A_i$  is greater than  $L_x$ , then the subsquare is entirely outside the disturbance and  $S_0$  is used in the grid at that subsquare. If the largest of the  $A_i$  is less than  $L_x$ , then the subsquare is entirely inside the disturbance and the value of  $S$  for that subsquare is interpolated from the input list of  $S_i$ . The remaining case is that of a subsquare on the edge of the disturbance. In this case the subsquare is subdivided into 16 smaller squares. Let the coordinates of the

center of each of these smaller squares be  $x_m$  and  $y_m$ . For each of these squares we calculate  $A_m$  using equation (16). The value of  $S$  for the subsquare is given by

$$S = \frac{nS_N - (16-n)S_0}{16} \quad (17)$$

where  $n$  is the number of subsquares which are within the ellipse. A circular disturbance is treated the same way as an elliptical one with  $R = 1$ .

#### IV. DESCRIPTION OF INPUT

All input to the sporadic-E program is given in a data deck on the standard input unit. A listing of sample input showing the data deck setup is shown in figure 2.

There are two parts to the input. This first part is read in by means of a FORTRAN NAMELIST input format. The first card of each set of input must contain '&DATUM' in columns 2-7. This is followed by at least one blank and then data items separated by commas. The data items have the following forms:

'variable name' = constant,

or

'array name' = set of constants (all separated by commas).

The data list is terminated by '&END'. All cards must have a blank in column 1.

The second part of the input follows the NAMELIST. The first card for this part is an identification card. It contains up to 80 columns of alphanumeric information and is used to label the output plots. Following the identification card a series of punched cards (obtained from the programs described in reference 14 with NPUNCH = 1) is input for each mode.

The first card gives the values of R, FREQ, AZIM, CODIP, MAGFLD, SIGMA and EPSR. Next there are two cards per mode. The first of these contains the complex eigenangle at the ground and values for the complex quantities T1 and T2. The second card contains the eigenangle at the ground (duplicate input) and values for T3 and T4. The quantities T1, T2, T3, and T4 are defined in reference 14.

```

1 8DATAUM
2 DM=6.75D6,
3 DMIN=150.,DMAX=15000.,DELD=150.,
4 YMAX=0.,DELY=0.,
5 IFLAG=2,IGRID=0.,
6 XO=2000.,YO=0.,
7 NUNK=4,NUMY=8,
8 SIZE=500.,SIZEY=1000.,
9 IPLOT=1,
10 XLNG=5.,YLNG=8.,
11 EXTC=3000.,WXTIC=3000.,WYTIC=1.,EYTIC=5.,
12 WHIN=6.,WMAX=2.,
13 EWIN=5.,EMAX=45.,
14 AEND
15 SAMPLE=X-VARIATION PLOT
16 R .000 F 0.0750 A 105.000 C 13.000 M 0.4100-004 S 3.200-004 E 10.
17 1 83.98519-34.969091 7.15494419-002 2.04701227+000-3.39161358-002 1.5526
18 2 83.98519-34.969091
19
20 R .000 F 0.0750 A 105.000 C 13.000 M 0.4100-004 S 3.200-004 E 10.
21 1 59.39295-65.552161-3.75059801-001 1.76435304+000 1.40913790+000 3.5235
22 2 59.39295-65.552161
23
24

```

Figure 2. Sample data input for the computer program.

The following variables and arrays may be specified in the NAMELIST  
input:

DM        dipole moment in ampere meters.

DMIN     the minimum range in kilometers at which fields are  
          calculated, printed, and plotted for IFLAG = 2.

DMAX     the maximum range in kilometers at which fields are calculated,  
          printed, and plotted for IFLAG = 2.

DELD     the increment, in kilometers at which fields are calculated,  
          printed, and plotted for IFLAG = 2.

YMAX     the maximum off axis value, in kilometers, at which fields are  
          calculated, printed, and plotted for IFLAG = 1.

DELY     the increment in kilometers, at which fields are calculated  
          printed and plotted for IFLAG = 1.

IFLAG    for IFLAG = 1 the program calculates fields as a function of y  
          - the distance is fixed at DMIN and the disturbance moves in the y  
          direction.  
          for IFLAG = 2 the program calculates fields as a function of  
          distance with the disturbance fixed.

IGRID    IGRID = 0 indicates that the disturbance is either square  
          or rectangular.  
          IGRID = 1 indicates that the disturbance is either circular or  
          elliptical.

X0,Y0    coordinates in kilometers at center of disturbance. Y0 is  
          also the initial value at which fields are calculated, printed,  
          and plotted for IFLAG = 1.

NUMX,  
NUMY     the disturbance is divided into NUMX grids in the x- direction  
          and NUMY grids in the y-direction (these are  $n_x$ ,  $n_y$  in the text).

SIZEX    defines the physical size of the disturbance. It is SIZEX  
SIZEY    kilometers by SIZEY kilometers.

IPLOT    a flag controlling whether or not plots are generated. If  
          IPLOT = 0 no plots are generated. If IPLOT = 1 two plots are  
          generated. For IFLAG=2 the first plot is WMAG(DB) vs X(KM),  
          equation (9). The second plot consists of two curves: EZUMAG  
          (DB), equations (13) and (4), is a solid curve and EZPMAG (DB),  
          equations (13) and (8), is a dashed curve. For IFLAG=1 WMAG,  
          EZUMAG, and EZPMAG are plotted with respect to y for a fixed value  
          of x.

XLNG the length in inches for the x-axis and y-axis for the  
 YLNG field plots.  
  
 WMIN the minimum and maximum values, in dB, desired on y-axis for  
 WMAX the WMAG plot.  
  
 EMIN the minimum and maximum values in DB desired on y-axis for  
 EMAX the EZREL plot.  
  
 XYIC the units per tic mark along the x-axis and y-axis for  
 YTIC both plots.

Initial values of the namelist variables are presented in table 1.

TABLE 1

Namelist variables and initial values.

<u>NAME</u>	<u>INITIAL VALUE</u>	<u>UNITS</u>
DM	6.75E6	Ampere meters
DMIN	25.0	Kilometers
DMAX	1000.0	Kilometers
DELD	25.0	Kilometers
YMAX	5000.0	Kilometers
DELY	25.0	Kilometers
IFLAG	2	
IGRID	0	
X0	0.0	Kilometers
Y0	0.0	Kilometers
NUM	0	
NUMY	0	
SIZEX	1000.0	Kilometers
SIZEY	1000.0	Kilometers
IPL0T	0	
XLNG	5.0	Inches
YLNG	6.0	Inches
WMIN	-6.0	Decibels
WMAX	2.0	Decibels
EMIN	-60	Decibels
EMAX	2.0	Decibels
XTIC	200.0	Kilometers
YTIC	0.2	Decibels

## V. DESCRIPTION OF OUTPUT

A listing of sample output is shown in figure 3. The resulting plots are found in figures 4 through 7. Figures 4 and 5 are the output from IFLAG = 2. Figures 6 and 7 are the output from IFLAG = 1. The first section of output is an echoing of the namelist input variables. This is followed by a schematic drawing of the disturbed region showing grid numbers and the coordinates of the center of the corner meshes. The next section shows additional input parameters: the identification label that will be on the plots, the frequency, conductivity, dielectric function, and the complex eigenangle and excitation factor for each region. YMID represents the y-value coordinate of the midpoint of the disturbance.

In the printout, the tables for WI, EZ0, and EZS, are the magnitudes of the quantities as given by equations 9, 10, and 13. These quantities are computed at the midpoints of each grid square.

The last table in the printout lists the following quantities at the given distance from the transmitter along the x-axis at y=0:

EZREL,EZANG	magnitude(dB) and phase angle (radians) of equation 8
WMAG,WANG	magnitude(dB) and phase angle (radians) of equation 9
EZUMAG,EZUANG	magnitude(dB) and phase angle (radians) of equation 10
EZPMAG,EZPANG	magnitude(dB) and phase angle (radians) of equation 13

```

$DATUM
DM = .67500000+007,DMIN = .15000000+003,DMAX = .15000000+005,DELD = .15000000+003,YMAX = .00000000
IFLAG = 2,IGRID = 0,X0 = .20000000+004,Y0 = .00000000,NUMY = 4,NUMX = 8,DELY = .00000000
SIZEX = .50000000+003,SIZEY = .10000000+004,IPL0T = 1,XLNG = .50000000+001,YLNG = .80000000+001,WMIN = -.60000000+001,
WMAX = .20000000+001,EMIN = .50000000+001,EMAX = .45000000+002,EXTIC = .30000000+004,EYTC = .50000000+001,WATC = .30000000+004,
WYTC = .10000000+001
SEND

```

?	?	?	?	?	?
?	1	?	2	?	3
?	?	?	?	?	4
?	?	?	?	?	?
?	?	?	?	?	?
?	5	?	6	?	7
?	?	?	?	?	8
?	?	?	?	?	?
?	?	?	?	?	?
?	9	?	10	?	11
?	?	?	?	?	12
?	?	?	?	?	?
?	?	?	?	?	?
?	?	?	?	?	?
?	13	?	14	?	15
?	?	?	?	?	16
?	?	?	?	?	?
?	?	?	?	?	?
?	17	?	18	?	19
?	?	?	?	?	20
?	?	?	?	?	?
?	?	?	?	?	?
?	?	?	?	?	?
?	21	?	22	?	23
?	?	?	?	?	24
?	?	?	?	?	?
?	?	?	?	?	?
?	25	?	26	?	27
?	?	?	?	?	28
?	?	?	?	?	?
?	?	?	?	?	?
?	?	?	?	?	?
?	29	?	30	?	31
?	?	?	?	?	32
?	?	?	?	?	?
?	?	?	?	?	?

```

COORDINATES AT CENTER OF MESH NUMBER 1 ARE: X= 1812.50 Y= 437.50
COORDINATES AT CENTER OF MESH NUMBER 4 ARE: X= 2187.50 Y= 437.50
COORDINATES AT CENTER OF MESH NUMBER 29 ARE: X= 1812.50 Y= -437.50
COORDINATES AT CENTER OF MESH NUMBER 32 ARE: X= 2187.50 Y= -437.50

```

Figure 3. Sample printed output generated by the first case called out in the sample data.

SAMPLE X-VARIATION PLOT  
 FREQ = .750-001 SIGMA = .320-003 EPSR= 10.00  
 GRID THETA XTRA  
 0 83.98519 -34.96909 -8.960733708-001 -9.687796474+000  
 1 59.39295 -65.55216 -2.835879266+000 -1.158006728+001

YMID = .00

EZO  
 1.51+000 1.45+000 1.39+000 1.34+000  
 1.55+000 1.48+000 1.42+000 1.30+000  
 1.57+000 1.50+000 1.44+000 1.30+000  
 1.59+000 1.51+000 1.45+000 1.38+000  
 1.59+000 1.51+000 1.45+000 1.38+000  
 1.57+000 1.50+000 1.44+000 1.38+000  
 1.55+000 1.48+000 1.42+000 1.36+000  
 1.51+000 1.45+000 1.39+000 1.34+000

EZS  
 1.13+000 1.03+000 9.84-001 9.64-001  
 1.11+000 1.02+000 9.83-001 9.73-001  
 1.10+000 1.01+000 9.80-001 9.78-001  
 1.09+000 1.00+000 9.78-001 9.80-001  
 1.09+000 1.00+000 9.78-001 9.80-001  
 1.10+000 1.01+000 9.80-001 9.78-001  
 1.11+000 1.02+000 9.83-001 9.73-001  
 1.13+000 1.03+000 9.84-001 9.64-001

WI  
 -2.5496 -2.9501 -3.0140 -2.8561  
 -2.8676 -3.2269 -3.1821 -2.9128  
 -3.1044 -3.4413 -3.3171 -2.9656  
 -3.2293 -3.5572 -3.3921 -2.9972  
 -3.2293 -3.5572 -3.3921 -2.9972  
 -3.1044 -3.4413 -3.3171 -2.9656  
 -2.8676 -3.2269 -3.1821 -2.9128  
 -2.5496 -2.9501 -3.0140 -2.8561

YMID	DIST	WMAG	WANG	EZREL	EZANG	EZUMAG	EZUANG	EZPMAG	EZPANG
.0	150.0	-1.18907-001	6.27277+000	-1.18907-001	3.13118+000	4.32795+001	4.58633+000	4.31606+001	1.43432+000
.0	300.0	-1.33171-001	6.25389+000	-1.33172-001	3.11230+000	3.80944+001	4.43830+000	3.79612+001	1.26741+000
.0	450.0	1.36797-003	6.23544+000	1.36797-003	3.09385+000	3.53506+001	4.24297+000	3.53520+001	1.05364+000
.0	600.0	2.62075-001	6.22922+000	2.62075-001	3.08763+000	3.35259+001	4.02089+000	3.37880+001	8.25135-001
.0	750.0	5.64055-001	6.24351+000	5.64055-001	3.10192+000	3.21635+001	3.78213+000	3.27276+001	6.00859-001
.0	900.0	7.95926-001	6.27982+000	7.95926-001	3.13823+000	3.10727+001	3.53314+000	3.18686+001	3.88183-001
.0	1050.0	8.52173-001	5.02191-002	8.52173-001	3.19181+000	3.01581+001	3.27715+000	3.10103+001	1.85776-001
.0	1200.0	6.44459-001	1.11490-001	6.44459-001	3.25308+000	2.93663+001	3.01626+000	3.00107+001	6.26935+000
.0	1350.0	1.01138-001	1.65756-001	1.01138-001	3.30735+000	2.86645+001	2.75183+000	2.87656+001	6.05918+000
.0	1500.0	-8.21781-001	1.44464-001	-8.21781-001	3.33130+000	2.80315+001	2.48476+000	2.72097+001	5.81606+000
.0	1650.0	-2.06253+000	1.44464-001	-2.06253+000	3.28606+000	2.74528+001	2.21567+000	2.53903+001	5.50173+000
.0	1800.0	-3.15872+000	-1.40568-002	-2.27585+000	3.05357+000	2.69181+001	1.94501+000	2.46422+001	4.99858+000
.0	1950.0	-3.54067+000	-1.98468-001	-2.65779+000	2.86916+000	2.64196+001	1.67311+000	2.37618+001	4.54227+000
.0	2100.0	-3.27364+000	-3.16967-001	-2.39076+000	2.75066+000	2.59516+001	1.40020+000	2.35608+001	4.15086+000
.0	2250.0	-2.81518+000	5.93701+000	-2.81518+000	2.79541+000	2.55097+001	1.12647+000	2.26945+001	3.92188+000
.0	2400.0	-2.49667+000	5.96869+000	-2.49667+000	2.82710+000	2.50903+001	8.52059-001	2.25936+001	3.67916+000
.0	2550.0	-2.27920+000	5.99499+000	-2.27920+000	2.85340+000	2.46906+001	5.77082-001	2.24114+001	3.43048+000
.0	2700.0	-2.12389+000	6.01585+000	-2.12389+000	2.87426+000	2.43083+001	3.01627-001	2.21844+001	3.17589+000

Figure 3. Continued.

2850.0	-2.00808+000	6.03243+000	-2.00808+000	2.89084+000	2.39415+001	2.57626-002	2.19334+001	2.91660+000
3000.0	-1.91812+000	6.04578+000	-1.91812+000	2.90419+000	2.35888+001	6.03273+000	2.15701+001	2.65373+000
3150.0	-1.84684+000	6.05670+000	-1.84684+000	2.91511+000	2.32482+001	5.75622+000	2.14013+001	2.38814+000
3300.0	-1.78124+000	6.06580+000	-1.78124+000	2.92420+000	2.29192+001	5.47944+000	2.11310+001	2.12045+000
3450.0	-1.73299+000	6.07347+000	-1.73299+000	2.93188+000	2.27008+001	5.20243+000	2.08613+001	1.85113+000
3600.0	-1.69769+000	6.08005+000	-1.69769+000	2.93845+000	2.22916+001	4.92522+000	2.05939+001	1.58048+000
3750.0	-1.66183+000	6.08574+000	-1.66183+000	2.94415+000	2.19915+001	4.64782+000	2.03297+001	1.30878+000
3900.0	-1.63055+000	6.09072+000	-1.63055+000	2.94913+000	2.16996+001	4.37027+000	2.00690+001	1.03621+000
4050.0	-1.60298+000	6.09512+000	-1.60298+000	2.95353+000	2.14152+001	4.09258+000	1.98122+001	7.62922-001
4200.0	-1.57945+000	6.09904+000	-1.57945+000	2.95744+000	2.11379+001	3.81475+000	1.95595+001	4.89010-001
4350.0	-1.55646+000	6.10255+000	-1.55646+000	2.96096+000	2.08674+001	3.53682+000	1.93109+001	2.14600-001
4500.0	-1.53658+000	6.10573+000	-1.53658+000	2.96413+000	2.06030+001	3.25877+000	1.90665+001	6.22291+000
4650.0	-1.51855-000	6.10861+000	-1.51855-000	2.96702+000	2.03446+001	2.98065+000	1.88260+001	5.94767+000
4800.0	-1.50198+000	6.11125+000	-1.50198+000	2.96965+000	2.00918+001	2.70242+000	1.85899+001	5.67207+000
4950.0	-1.48683+000	6.11366+000	-1.48683+000	2.97207+000	1.98442+001	2.42413+000	1.83574+001	5.39620+000
5100.0	-1.47280+000	6.11590+000	-1.47280+000	2.97430+000	1.96018+001	2.14577+000	1.81290+001	5.12007+000
5250.0	-1.45936+000	6.11796+000	-1.45936+000	2.97637+000	1.93638+001	1.86736+000	1.79040+001	4.84372+000
5400.0	-1.44711+000	6.11988+000	-1.44711+000	2.97829+000	1.91308+001	1.58886+000	1.76831+001	4.56714+000
5550.0	-1.43623+000	6.12165+000	-1.43623+000	2.98006+000	1.89018+001	1.31026+000	1.74654+001	4.29032+000
5700.0	-1.42603+000	6.12333+000	-1.42603+000	2.98173+000	1.86762+001	1.03177+000	1.72502+001	4.01350+000
5850.0	-1.41600+000	6.12490+000	-1.41600+000	2.98330+000	1.84554+001	7.53127-001	1.70394+001	3.73643+000
6000.0	-1.40607+000	6.12638+000	-1.40607+000	2.98479+000	1.82404+001	4.74266-001	1.68343+001	3.45906+000
6150.0	-1.39690+000	6.12774+000	-1.39690+000	2.98615+000	1.80269+001	1.95346-001	1.66300+001	3.18149+000
6300.0	-1.38855+000	6.12902+000	-1.38855+000	2.98743+000	1.78157+001	6.19374+000	1.64271+001	2.90398+000
6450.0	-1.38083+000	6.13030+000	-1.38083+000	2.98871+000	1.76093+001	5.92111+000	1.62290+001	2.62664+000
6600.0	-1.37028+000	6.13152+000	-1.37028+000	2.98992+000	1.74157+001	5.64130+000	1.60455+001	2.34804+000
6750.0	-1.36380+000	6.13256+000	-1.36380+000	2.99077+000	1.72116+001	5.36250+000	1.58478+001	2.07028+000
6900.0	-1.35835+000	6.13375+000	-1.35835+000	2.99154+000	1.70193+001	5.08374+000	1.56629+001	1.79271+000
7050.0	-1.35141+000	6.13486+000	-1.35141+000	2.99277+000	1.68231+001	4.80571+000	1.54717+001	1.51580+000
7200.0	-1.34480+000	6.13586+000	-1.34480+000	2.99427+000	1.66335+001	4.52677+000	1.52786+001	1.23786+000
7350.0	-1.33843+000	6.13683+000	-1.33843+000	2.99523+000	1.64468+001	4.24780+000	1.51084+001	9.59848-001
7500.0	-1.33235+000	6.13775+000	-1.33235+000	2.99616+000	1.62631+001	3.96881+000	1.49307+001	6.81783-001
7650.0	-1.32640+000	6.13865+000	-1.32640+000	2.99705+000	1.60822+001	3.68979+000	1.47558+001	4.03664-001
7800.0	-1.32069+000	6.13952+000	-1.32069+000	2.99793+000	1.59041+001	3.41076+000	1.45834+001	1.25504-001
7950.0	-1.31509+000	6.14035+000	-1.31509+000	2.99876+000	1.57283+001	3.13171+000	1.44137+001	6.13047+000
8100.0	-1.30953+000	6.14117+000	-1.30953+000	2.99958+000	1.55561+001	2.85264+000	1.42466+001	5.85222+000
8250.0	-1.30415+000	6.14196+000	-1.30415+000	3.00037+000	1.53861+001	2.57356+000	1.40820+001	5.57392+000
8400.0	-1.29907+000	6.14276+000	-1.29907+000	3.00116+000	1.52183+001	2.29446+000	1.39197+001	5.29562+000
8550.0	-1.29408+000	6.14349+000	-1.29408+000	3.00190+000	1.50540+001	2.01534+000	1.37599+001	5.01724+000
8700.0	-1.28961+000	6.14420+000	-1.28961+000	3.00260+000	1.48918+001	1.73621+000	1.36022+001	4.73881+000
8850.0	-1.28456+000	6.14496+000	-1.28456+000	3.00337+000	1.47321+001	1.45707+000	1.34475+001	4.46044+000
9000.0	-1.28031+000	6.14560+000	-1.28031+000	3.00400+000	1.45743+001	1.17791+000	1.32946+001	4.18192+000
9150.0	-1.27437+000	6.14628+000	-1.27437+000	3.00469+000	1.44202+001	8.98744-001	1.31453+001	3.90343+000
9300.0	-1.26933+000	6.14692+000	-1.26933+000	3.00532+000	1.42680+001	6.19564-001	1.29980+001	3.62489+000
9450.0	-1.26536+000	6.14757+000	-1.26536+000	3.00598+000	1.41182+001	3.40373-001	1.28528+001	3.34635+000
9600.0	-1.26141+000	6.14821+000	-1.26141+000	3.00661+000	1.39709+001	6.11717-002	1.27100+001	3.06779+000
9750.0	-1.25837+000	6.14884+000	-1.25837+000	3.00724+000	1.38259+001	6.06515+000	1.25696+001	2.78720+000
9900.0	-1.25516+000	6.14945+000	-1.25516+000	3.00786+000	1.36834+001	5.78592+000	1.24315+001	2.51060+000
10050.0	-1.24758+000	6.15007+000	-1.24758+000	3.00847+000	1.35434+001	5.50669+000	1.22958+001	2.23198+000
10200.0	-1.24324+000	6.15067+000	-1.24324+000	3.00908+000	1.34057+001	5.22746+000	1.21625+001	1.95335+000
10350.0	-1.23893+000	6.15127+000	-1.23893+000	3.00967+000	1.32705+001	4.94821+000	1.20316+001	1.67470+000
10500.0	-1.23464+000	6.15186+000	-1.23464+000	3.01026+000	1.31377+001	4.66895+000	1.19030+001	1.39603+000
10650.0	-1.23038+000	6.15244+000	-1.23038+000	3.01085+000	1.30073+001	4.38969+000	1.17769+001	1.11735+000
10800.0	-1.22613+000	6.15302+000	-1.22613+000	3.01143+000	1.28794+001	4.11042+000	1.16532+001	8.38661-001
10950.0	-1.22189+000	6.15359+000	-1.22189+000	3.01200+000	1.27539+001	3.83114+000	1.15320+001	5.59959+000
11100.0	-1.21766+000	6.15417+000	-1.21766+000	3.01257+000	1.26309+001	3.55186+000	1.14132+001	2.81246-001
11250.0	-1.21342+000	6.15473+000	-1.21342+000	3.01314+000	1.25103+001	3.27257+000	1.12969+001	2.52413-003

Figure 3. Continued.

.0	11400.0	-1.2019+000	6.15530+000	-1.2031R+000	3.01371+000	1.23423+001	2.99327+000	1.11831+001	6.00698+000
.0	11550.0	-1.2049+000	6.15587+000	-1.2059+000	3.01427+000	1.22768+001	2.71397+000	1.10719+001	5.72824+000
.0	11700.0	-1.20069+000	6.15643+000	-1.2006R+000	3.01484+000	1.21639+001	2.43466+000	1.09632+001	5.44950+000
.0	11850.0	-1.19641+000	6.15699+000	-1.19641+000	3.01540+000	1.20536+001	2.15535+000	1.08572+001	5.17075+000
.0	12000.0	-1.19211+000	6.15756+000	-1.19211+000	3.01595+000	1.19459+001	1.87693+000	1.07538+001	4.89199+000
.0	12150.0	-1.18778+000	6.15812+000	-1.1877R+000	3.01653+000	1.18408+001	1.59570+000	1.06531+001	4.61323+000
.0	12300.0	-1.18342+000	6.15869+000	-1.18342+000	3.01709+000	1.17385+001	1.31737+000	1.05551+001	4.33447+000
.0	12450.0	-1.17903+000	6.15926+000	-1.17903+000	3.01766+000	1.16389+001	1.03804+000	1.04599+001	4.05570+000
.0	12600.0	-1.17459+000	6.15983+000	-1.17459+000	3.01823+000	1.15422+001	7.58598-001	1.03676+001	3.77693+000
.0	12750.0	-1.17011+000	6.16040+000	-1.17011+000	3.01881+000	1.14482+001	4.79354-001	1.02781+001	3.49816+000
.0	12900.0	-1.16557+000	6.16098+000	-1.16557+000	3.01939+000	1.13572+001	2.00006-001	1.01917+001	3.21939+000
.0	13050.0	-1.16047+000	6.16157+000	-1.16097+000	3.01997+000	1.12692+001	6.20384+000	1.01083+001	2.94063+000
.0	13200.0	-1.15630+000	6.16216+000	-1.15630+000	3.02056+000	1.11843+001	5.92448+000	1.00280+001	2.66186+000
.0	13350.0	-1.15157+000	6.16275+000	-1.15157+000	3.02116+000	1.11025+001	5.64512+000	9.95089+000	2.38310+000
.0	13500.0	-1.14675+000	6.16336+000	-1.14675+000	3.02176+000	1.10233+001	5.36576+000	9.87710+000	2.10434+000
.0	13650.0	-1.14185+000	6.16397+000	-1.14185+000	3.02237+000	1.09486+001	5.08539+000	9.80671+000	1.82558+000
.0	13800.0	-1.13685+000	6.16459+000	-1.13685+000	3.02300+000	1.08767+001	4.80702+000	9.73982+000	1.54683+000
.0	13950.0	-1.13176+000	6.16522+000	-1.13176+000	3.02363+000	1.08083+001	4.52765+000	9.67655+000	1.26809+000
.0	14100.0	-1.12655+000	6.16586+000	-1.12655+000	3.02427+000	1.07436+001	4.24827+000	9.61703+000	9.89353-001
.0	14250.0	-1.12122+000	6.16651+000	-1.12122+000	3.02492+000	1.06828+001	3.96889+000	9.56138+000	7.10626-001
.0	14400.0	-1.11576+000	6.16718+000	-1.11576+000	3.02559+000	1.06255+001	3.68951+000	9.50976+000	4.31909-001
.0	14550.0	-1.11016+000	6.16786+000	-1.11016+000	3.02627+000	1.05725+001	3.41012+000	9.46232+000	1.53204-001
.0	14700.0	-1.10441+000	6.16856+000	-1.10441+000	3.02697+000	1.05237+001	3.13073+000	9.41925+000	6.15770+000
.0	14850.0	-1.09850+000	6.16928+000	-1.09850+000	3.02768+000	1.04792+001	2.85134+000	9.38074+000	5.87902+000
.0	15000.0	-1.09240+000	6.17001+000	-1.09240+000	3.02842+000	1.04394+001	2.57194+000	9.34699+000	5.60036+000

21

PLOTTING COMMENCING  
.....

..... DISSPLA VERSION 9.0 .....  
NO. OF FIRST PLOT 1

PLOT NO. 1 WITH THE TITLE

HAS BEEN COMPLETED.

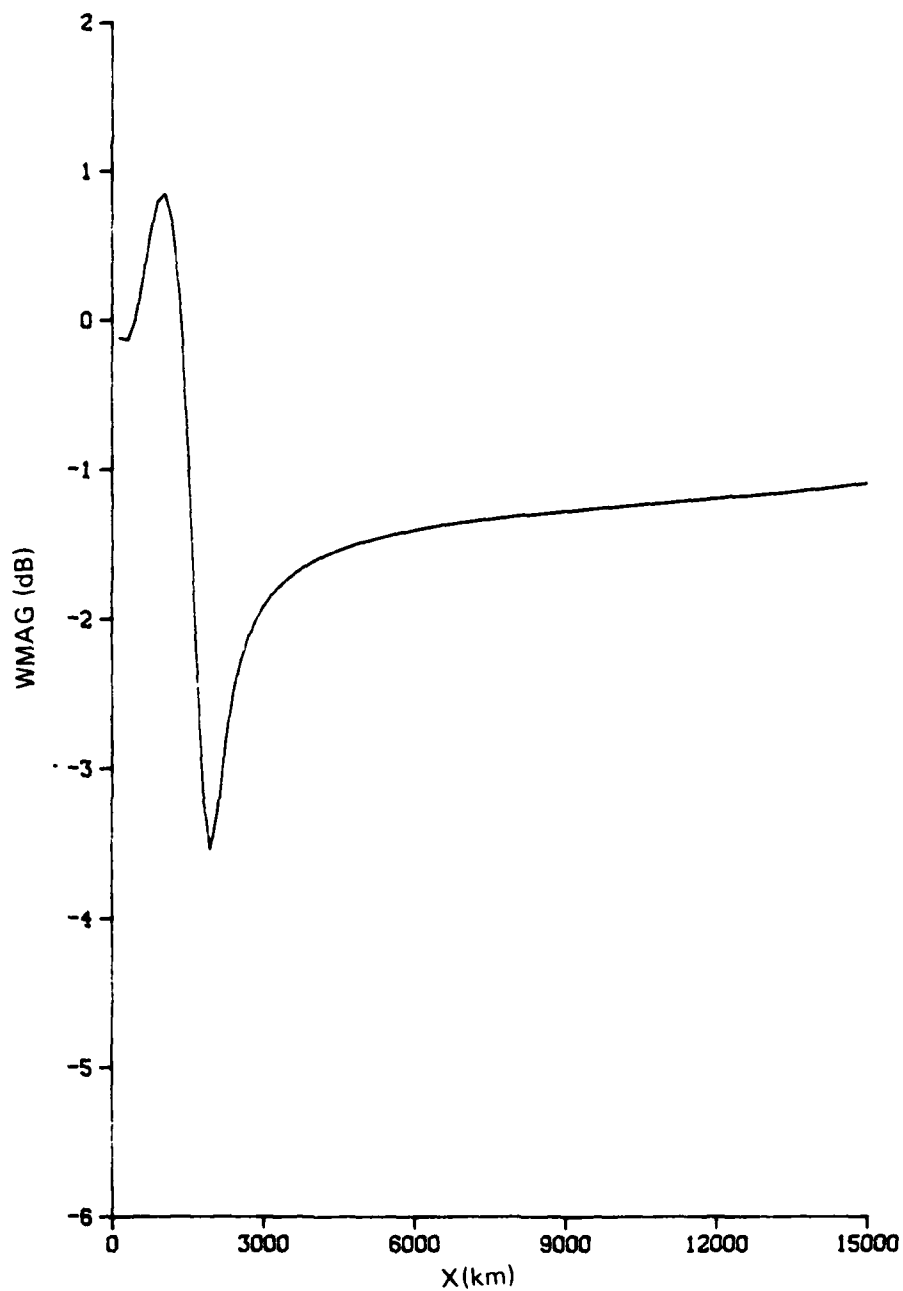
PLOT ID. READS  
PLOT 1 11.03.23 THUR 23 SEP, 1982  
JOB=SPORAD , DISSPLA 9.0

DATA FOR PLOT

NO. OF CURVES DRAWN 1

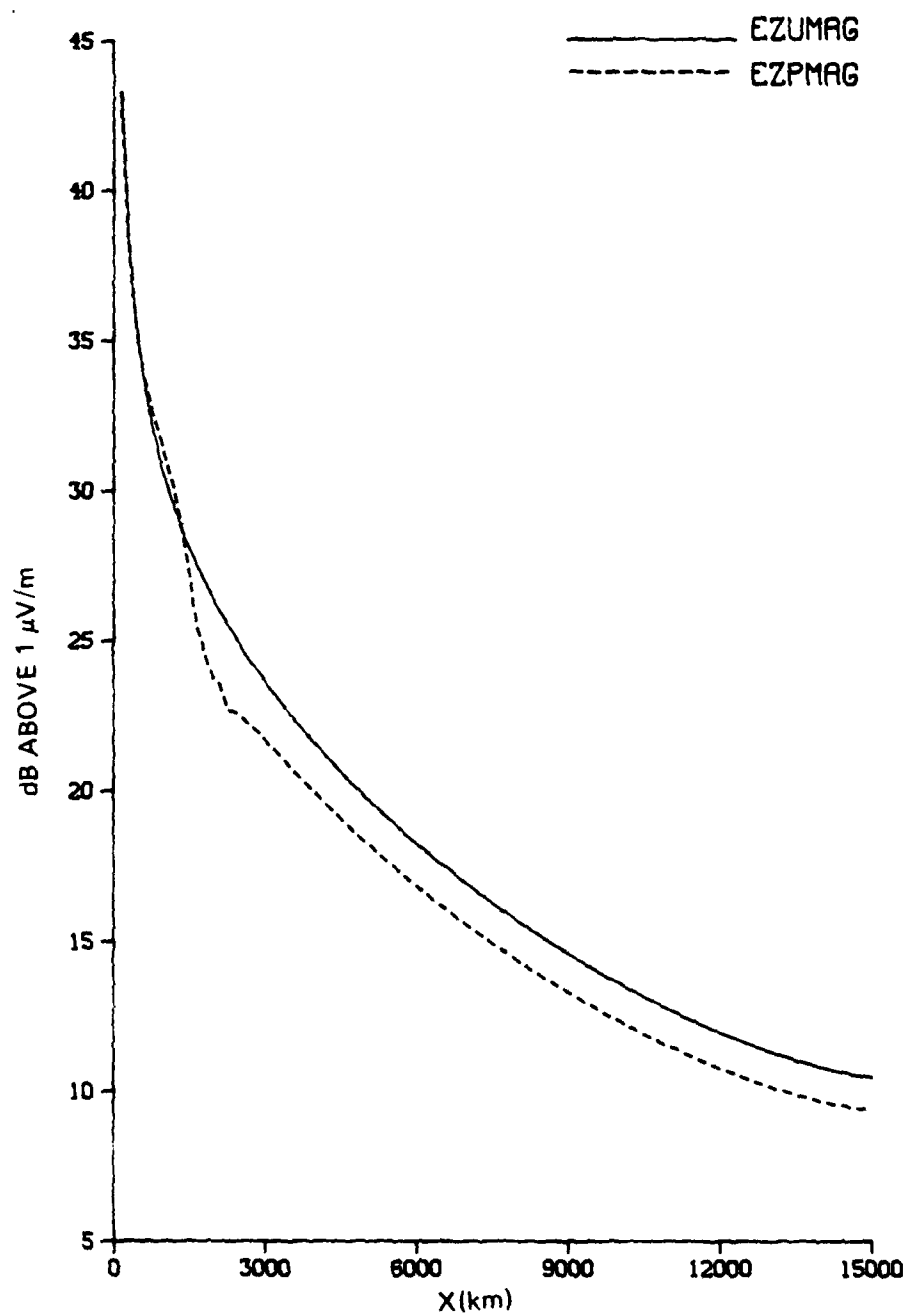
-----  
HORIZ. AXIS LENGTH 5.0 INS.  
VERT. AXIS LENGTH 8.0 INS.

Figure 3. Continued.



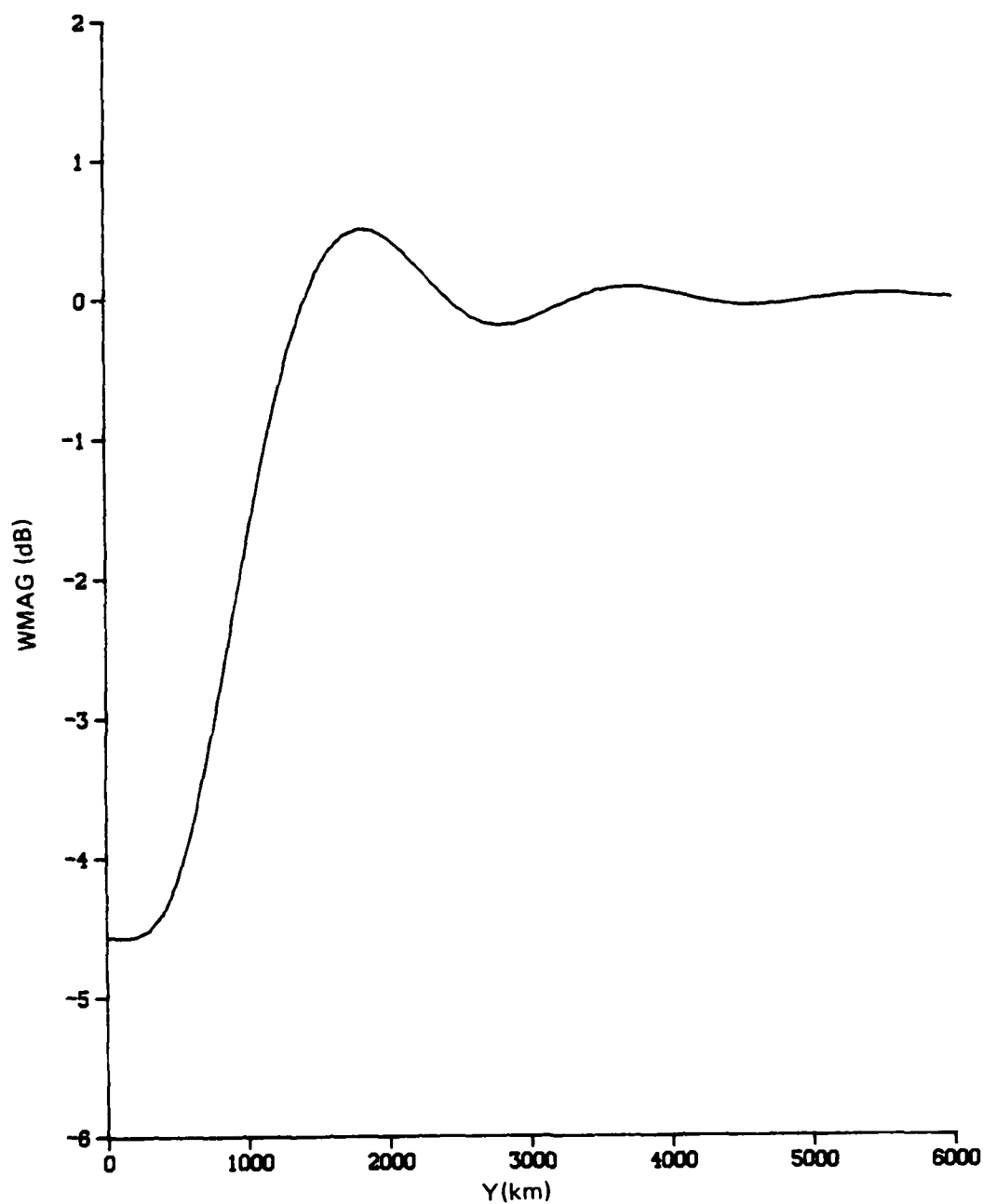
SAMPLE X-VARIATION PLOT  
SQUARE OR RECTANGULAR DISTURBANCE  
FREQ = 0.075  
SIZEX- 500.0 XO- 2000.0 NUMX- 4  
SIZEY- 1000.0 YO- 0.0 NUMY- 8

Figure 4. Sample x-variation plot for WMAG assuming a rectangular disturbance.



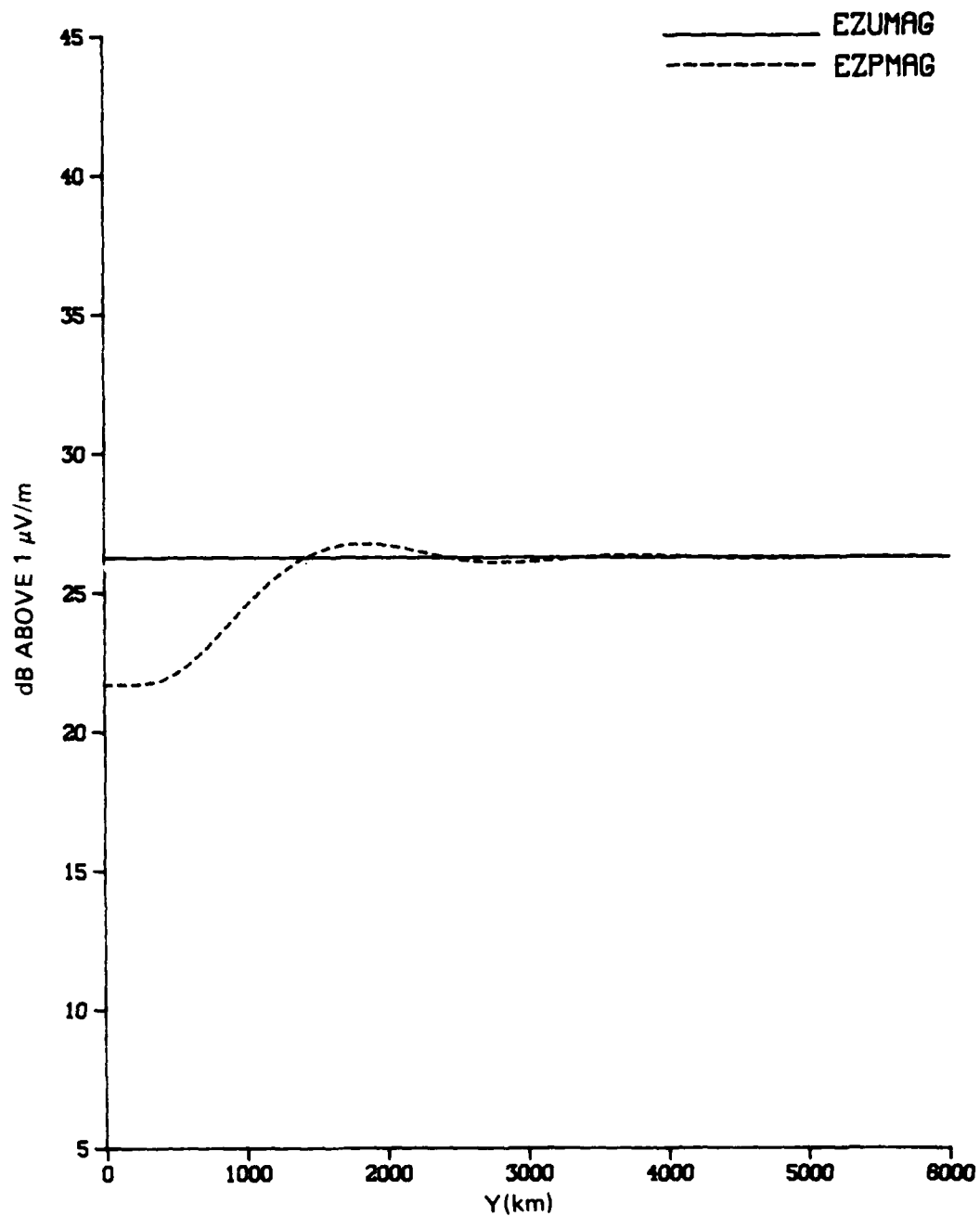
SAMPLE X-VARIATION PLOT  
 SQUARE OR RECTANGULAR DISTURBANCE  
 FREQ - 0.075  
 SIZEX- 500.0 XO- 2000.0 NUMX- 4  
 SIZEY- 1000.0 YO- 0.0 NUMY- 8

Figure 5. Sample x-variation plot for EZUMAG and EZPMAG assuming a rectangular disturbance.



SAMPLE Y-VARIATION PLOT  
SQUARE OR RECTANGULAR DISTURBANCE  
FREQ = 0.075 DMIN = 2000.0  
SIZEX- 1000.0 XO- 1000.0 NUMX- 5  
SIZEY- 1000.0 YO- 0.0 NUMY- 5

Figure 6. Sample y-variation plot for WMAG assuming a rectangular disturbance.



SAMPLE Y-VARIATION PLOT  
 SQUARE OR RECTANGULAR DISTURBANCE  
 FREQ = 0.075 DMIN = 2000.0  
 SIZEX- 1000.0 XO- 1000.0 NUMX- 5  
 SIZEY- 1000.0 YO- 0.0 NUMY- 5

Figure 7. Sample y-variation plot for EZUMAG and EZPMAG assuming a rectangular disturbance.

## VI. PROGRAM CHECKS

Several program checks have been made of flat earth geometry cases which can be solved in terms of well known functions. In each case the disturbance is azimuthally symmetric with the transmitter located at the origin.

The first case considered is that of a uniform circular disturbance for which

$$\begin{aligned} S^2 &= S_p^2 & \text{for } r < r_0 \\ S^2 &= S_0^2 & \text{for } r > r_0 \end{aligned} \quad (18)$$

For this case the solution for the ratio of the disturbed lateral function,

$\Psi$ , to the undisturbed,  $\Psi^i$  is for  $r < r_0$

$$\frac{\Psi}{\Psi^i} = \frac{S_p}{S_0 H_1^{(2)}(kS_0 r)} \left\{ H_1^{(2)}(kS_p r) - \frac{(H_1^{(2)}(kS_p r_0) h(kS_0 r_0) - h(kS_p r_0) H_1^{(2)}(kS_0 r_0))}{(J_1(kS_p r_0) h(kS_0 r_0) - j(kS_p r_0) H_1^{(2)}(kS_0 r_0))} J_1(kS r) \right\} \quad (19)$$

and for  $r > r_0$

$$\frac{\Psi}{\Psi^i} = \frac{S_p}{S_0} \left\{ \frac{H_1^{(2)}(kS_p r_0) j(kS_p r_0) - h(kS_p r_0) J_1(kS_p r_0)}{H_1^{(2)}(kS_0 r_0) j(kS_p r_0) - h(kS_0 r_0) J_1(kS_p r_0)} \right\} \quad (20)$$

In these equations

$$h(x) = \frac{x}{2} [H_0^{(2)}(x) - H_2^{(2)}(x)] \quad (21)$$

$$j(x) = \frac{x}{2} [J_0(x) - J_2(x)] \quad (22)$$

It is clear from equation (20) that  $\psi/\psi^i$  is constant for  $r \geq r_0$  as expected. Figure 8 shows the results calculated by using equation (19) along with the moment method results. The radius  $r_0$  is 500 km. The unperturbed eigenangle is  $(83.985^\circ, -34.909^\circ)$  or equivalently  $S_0 = (1.185, -0.0681i)$  and the perturbed eigenangle is  $(59.393^\circ, -65.552^\circ)$  or equivalently  $S_p = (1.488, -0.718i)$ .  $S_0$  is appropriate to a nighttime ambient ionosphere at 75 Hz, whereas,  $S_p$  is appropriate to a nighttime ionosphere with a sporadic E layer<sup>9</sup>. The 13 x 13 mesh results give agreement to within a few hundredths of a dB of the exact results. In the moments method, the lateral function is calculated at the center points of each square mesh and the lateral function is linearly interpolated between those points. Because of approximations made in the slab containing the transmitter, the first meaningful data point obtained from the moment method is the first point to fall in a slab adjacent to that containing the transmitter. This explains the starting ranges for the moment method results.

A second check case considered is that of a circular disturbance which is uniform out to a radius  $r_0$ , then falls off as  $1/r^2$  between  $r_0$ , and  $r_1$ , and is equal to  $S_0$  beyond  $r_1$ . The mathematical description of  $S$  is

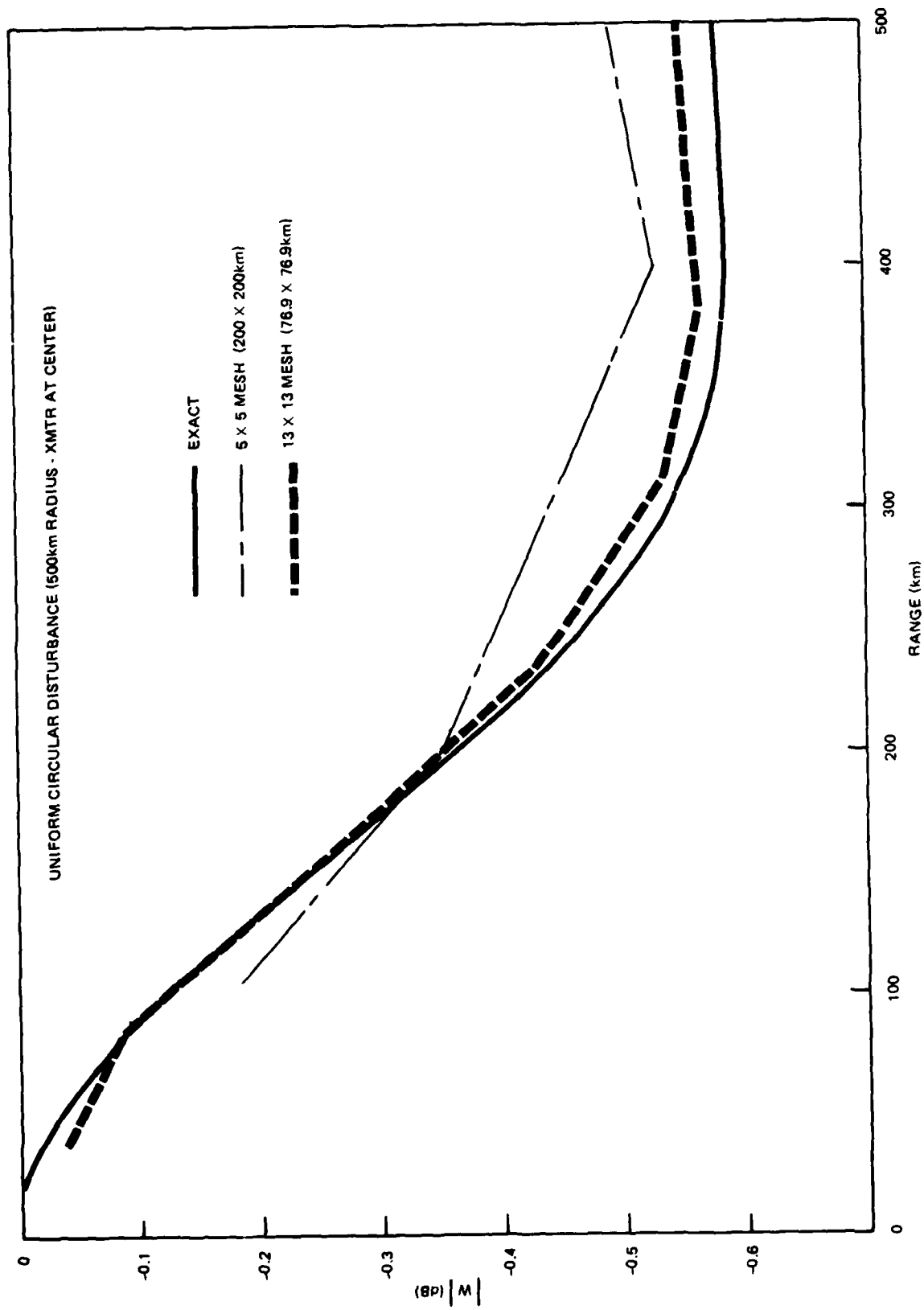


Figure 8. Comparison between analytic solution and the computer program output for problem 1: a uniform circular disturbance.

$$\begin{aligned}
s^2 &= s_p^2 & ; r < r_0 \\
s^2 &= s_0^2 + (s_p^2 - s_0^2) r_0^2 / r^2 & ; r_0 < r < r_1 \\
s^2 &= s_0^2 & ; r > r_1
\end{aligned} \tag{23}$$

When the transmitter is at the center of the disturbance the solution for the ratio of the disturbed lateral function,  $\psi$ , to the undisturbed,  $\psi^i$ , is for  $r < r_0$

$$\frac{\psi}{\psi^i} = \frac{1}{s_0 H_1^{(2)}(ks_0 r)} [SH_1^{(2)}(ks_p r) + aJ_1(ks_p r)] ; r < r_0 \tag{24}$$

$$\frac{\psi}{\psi^i} = \frac{1}{s_0 H_1^{(2)}(ks_0 r)} [bJ_v(ks_0 r) + dJ_{-v}(ks_0 r)] ; r_0 < r < r_1 \tag{25}$$

$$\frac{\psi}{\psi^i} = \frac{T}{s_0} ; r < r_1 \tag{26}$$

In these equations

$$v = [1 - (s_p^2 - s_0^2) (kr_0)^2]^{1/2} \tag{27}$$

$$a = \frac{1}{\Delta} \begin{vmatrix} SH_1^{(2)}(ks_p r_0) & J_v(ks_0 r_0) & J_{-v}(ks_0 r_0) & 0 \\ Sh_1(ks_p r_0) & j_v(ks_0 r_0) & j_{-v}(ks_0 r_0) & 0 \\ 0 & J_v(ks_0 r_1) & J_{-v}(ks_0 r_1) & -H_1^{(2)}(ks_0 r_1) \\ 0 & j_v(ks_0 r_1) & j_{-v}(ks_0 r_1) & -h_1(ks_0 r_1) \end{vmatrix} \tag{28}$$

$$b = \frac{1}{\Delta} \begin{vmatrix} -J_1(kS_p r_0) & SH_1^{(2)}(kS_p r_0) & J_{-v}(kS_0 r_0) & 0 \\ -j_1(kS_p r_0) & Sh_1(kS_p r_0) & j_{-v}(kS_0 r_0) & 0 \\ 0 & 0 & J_{-v}(kS_0 r_1) & -H_1^{(2)}(kS_0 r_1) \\ 0 & 0 & j_{-v}(kS_0 r_1) & -h_1(kS_0 r_1) \end{vmatrix} \quad (29)$$

$$d = \frac{1}{\Delta} \begin{vmatrix} -J_1(kS_p r_0) & J_v(kS_0 r_0) & SH_1^{(2)}(kS_p r_0) & 0 \\ -j_1(kS_p r_0) & j_v(kS_0 r_0) & Sh_1(kS_p r_0) & 0 \\ 0 & J_v(kS_0 r_1) & 0 & -H_1^{(2)}(kS_0 r_1) \\ 0 & j_v(kS_0 r_1) & 0 & -h_1(kS_0 r_1) \end{vmatrix} \quad (30)$$

$$T = \frac{1}{\Delta} \begin{vmatrix} -J_1(kS_p r_0) & J_v(kS_0 r_0) & J_{-v}(kS_0 r_0) & -SH_1^{(2)}(kS_p r_0) \\ -j_1(kS_p r_0) & j_v(kS_0 r_0) & j_{-v}(kS_0 r_0) & Sh_1(kS_p r_0) \\ 0 & J_v(kS_0 r_1) & J_{-v}(kS_0 r_1) & 0 \\ 0 & j_v(kS_0 r_1) & j_{-v}(kS_0 r_1) & -h_1(kS_0 r_1) \end{vmatrix} \quad (31)$$

$$\Delta = \begin{vmatrix} -J_1(kS_p r_0) & J_v(kS_0 r_0) & J_v(kS_0 r_0) & 0 \\ -j_1(kS_p r_0) & j_v(kS_0 r_0) & j_{-v}(kS_0 r_0) & 0 \\ 0 & J_v(kS_0 r_1) & J_{-v}(kS_0 r_1) & -H_1^{(2)}(kS_0 r_1) \\ 0 & j_v(kS_0 r_1) & j_{-v}(kS_0 r_1) & -h_1(kS_0 r_1) \end{vmatrix} \quad (32)$$

$$j_q(x) = \frac{x}{2} [J_{q-1}(x) - J_{q+1}(x)] \quad (33)$$

$$h_q(k) = \frac{x}{2} [H_{q-1}^{(2)}(x) - H_{q+1}^{(2)}(x)] \quad (34)$$

Again it is clear from equation (26) that  $\psi/\psi^i$  is constant for  $r > r_1$ . Figure 9 shows results for  $r_0 = 300$  km,  $r_1 = 1000$  km and the same  $S_0$  and  $S_p$  used for the results of figure 8. The moment method results are for a 10 x 10 mesh and the results beyond 100 km agree with the exact values to better than a tenth of a dB.

A third check based on the model described by equations (23) is shown in figure 10.  $S_0$  and  $S_p$  are assigned the same values as for figure 8; however,  $r_0$  has been taken equal to 588 km and  $r_1 = 2000$  km. The moment method result is for a 17 x 17 mesh which is the largest the program can handle because of storage limitations. The mesh size in this instance is approximately 235 km. In this connection Hagmann et al<sup>13</sup>, state that the mesh size must be less than  $155 \lambda_0$  where  $\lambda_0$  is the unperturbed wavelength. In the present case of 75 Hz,  $\lambda_0 \approx 4000/S_{0r} \approx 3375$  km. This would give a maximum cell size of  $\approx 523$  km. It has been our experience that approaching this limit leads to substantial error and it would probably be best at 75 Hz not to exceed mesh sizes of several hundred kilometers. This would limit the linear dimension of the disturbance to something on the order of 5000 km at 75 Hz. Figure 10 shows the agreement between the exact calculation and the moment method to be within a few tenths of a dB. It is also very likely true that the cases checked are some of the most difficult for the moment method to handle because the gradient of the incident field is largest close to the transmitter. Thus, it would be expected that for disturbances remote from the transmitter better accuracy would be obtained for the same mesh size.

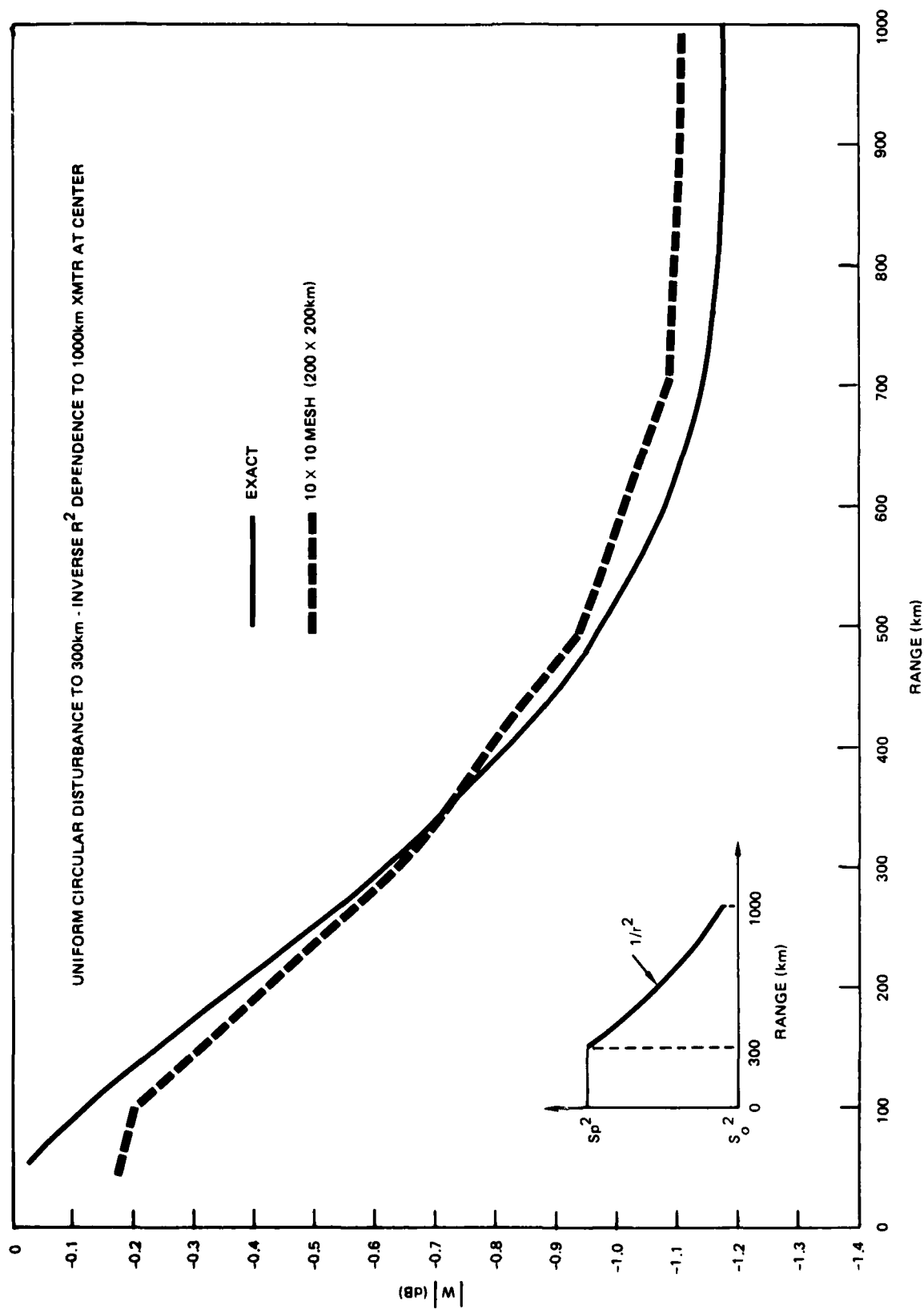


Figure 9. Comparison between analytic solution and the computer program output for problem 2: a uniform circular disturbance to  $r_0$  with an inverse  $r^2$  dependence of  $S_p$  between  $r_0$  and  $r_1$  using a  $10 \times 10$  mesh.

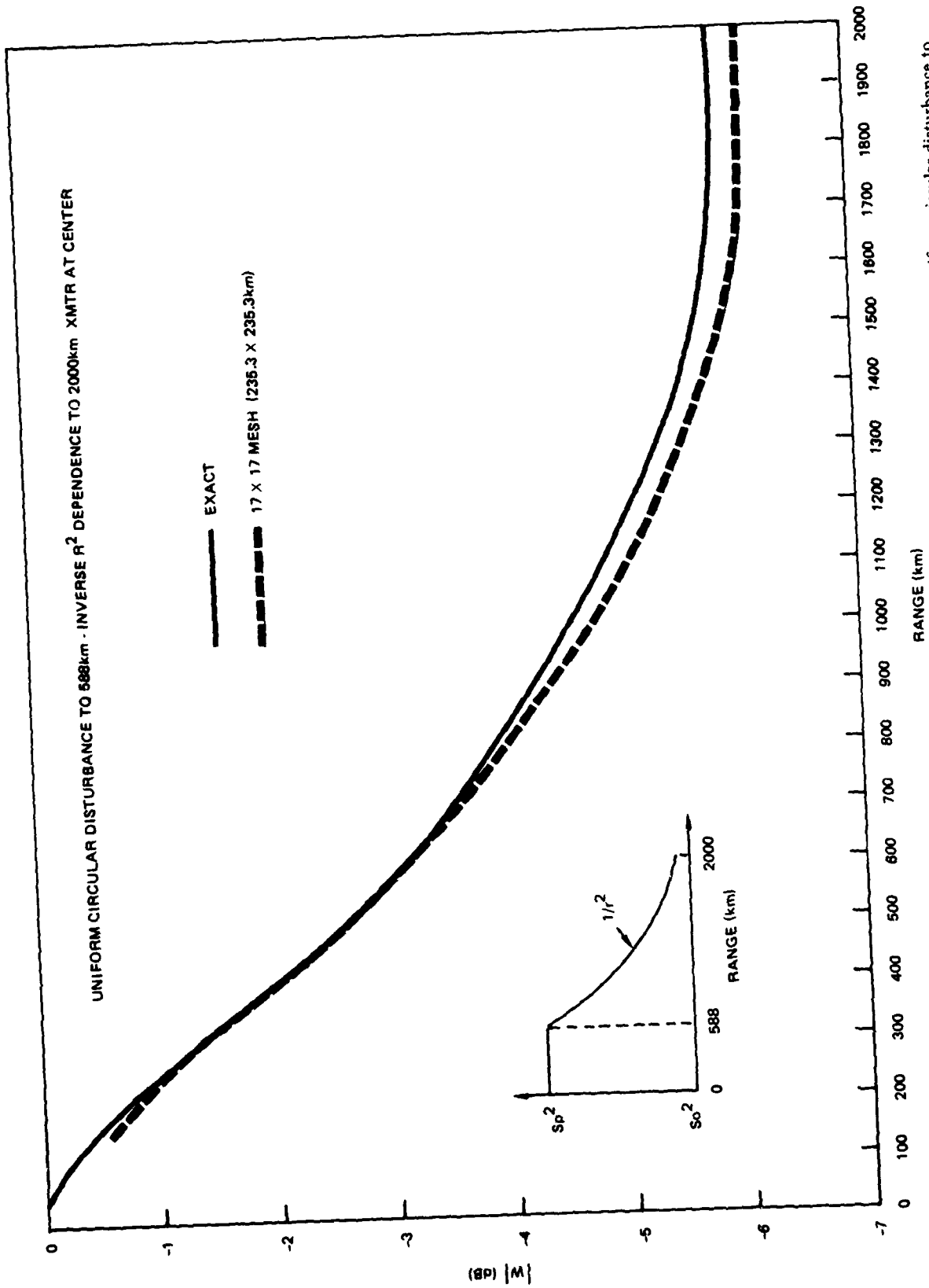


Figure 10. Comparison between analytic solution and the computer program output for problem 3: a uniform circular disturbance to  $r_0$  with an inverse  $r^2$  dependence of  $S_p$  between  $r_0$  and  $r_1$  using a  $17 \times 17$  mesh.

## VII. REFERENCES

1. Wait, JR, On phase changes in very low frequency propagation induced by an ionospheric depression of finite extent, J Geophys Res, vol 69, No 3, pp 441-445, 1964
2. Galejs, J, ELF propagation in an inhomogeneous waveguide, Radio Sci, vol 6, No 7, pp 727-736, 1971
3. Greifinger, C and P Greifinger, Effect of a cylindrically-symmetric ionospheric disturbance on ELF propagation in the earth ionosphere waveguide, DNA4339T, prepared for DNA by R&D Associates, June 1977
4. Field, EC, ELF propagation in a non-stratified earth-ionosphere waveguide, Pacific Sierra Report 806, April 1978
5. Field, EC, An integral-equation approach to ELF propagation in a non-stratified earth-ionosphere waveguide, Pacific Sierra Report 904, February 1979
6. Field, EC and RG Joiner, An integral-equation approach to long wave propagation in a non-stratified earth-ionosphere waveguide, Radio Sci, vol 14, No 6, pp 1057-1068, 1979
7. Field, EC and RG Joiner, Effects of lateral ionospheric gradients on ELF propagation, Radio Sci, vol 17, No 3, pp 693-700, 1982
8. Pappert, RA, Effects of a large patch of sporadic-E on night-time propagation at lower ELF, J Atmos Terr Physics, vol 42, pp 417-425, 1980
9. Pappert, RA and WF Moler, Propagation theory and calculations at extremely low frequencies (ELF), IEEE Transactions on Communications, vol com-22, No 4, pp 438-448, 1974
10. Pappert, RA and WF Moler, A theoretical study of ELF normal mode reflection and absorption produced by night-time ionospheres, J Atmos Terr Physics, vol 40, pp 1031-1045, 1978
11. Harrington, RF, Field Computation by Moment Methods, The Macmillan Company, New York, 1968
12. Pappert, RA, WF Moler and LR Shockey, A fortran program for waveguide propagation which allows for both vertical and horizontal dipole excitation, Interim Report No 702, prepared by the Naval Electronics Laboratory Center for the Defense Atomic Support Agency, June 1970
13. Hagmann, MJ, OP Gandhi and CH Durney, Procedures for improving convergence of moment method solutions in electromagnetics, IEEE Trans Antennas and Propagation, AP-26, pp 713-748, 1978

14. Morfitt, DG, CH Shellman, "MODESRCH", An improved computer program for obtaining elf/vlf/lf mode constants in an earth-ionosphere waveguide, DNA Interim Report 77T, 1 October 1976

VIII. APPENDIX: PROGRAM LISTING

PRECEDING PAGE BLANK-NOT FILMED

@FTN,USFO SPORAD.MAIN  
FTN 10R1A 09/22/82-11:32(9,10)

```

1. C
2. C SPORADIC-E PROGRAM FOR ELF
3. C
4. C IMPLICIT COMPLEX (A-H,O-Z)
5. C
6. C PARAMETER MAXNX=12,NDIM=100,NRPTS=500
7. C
8. C MAXNX IS THE MAX NUMBER OF DISTURBED EIGENS WHICH CAN BE INPUT
9. C NDIM IS THE MAX VALUE OF NUMX*NUMY
10. C NRPTS IS THE MAX NUMBER OF POINTS TO PLOT
11. C
12. C COMPLEX IM/(0.E0,1.E0)/,J1,J2,NGX,IM,KSO,NGSQ,
13. $ A(NDIM,NDIM),
14. $ EZO(NDIM),EZO(NDIM),SD(YDIM),XTRD(NDIM),WI(NDIM),
15. $ SI(MAXNX),XTRI(MAXNX)
16. C
17. C REAL XM,IM,XGSO,AI,SIZEX,SIZEY,XDINC,XO,YO,YOVERX,DELTAX,
18. $ DELTAY,X1,Y1,XINC,YINC,EPSP,RHOMN,EZREL,EZANG,KA,DELY,
19. $ YMAX,F,WAG,WANG,YMID,OMEGA,RADIUS,WAVENO,FREQ,SIGMA,
20. $ ERH,DIST,DMIN,DM,DELD,DMAX,HXINC,HYINC,RG,AIMAX,DST,
21. $ RGMAX,RGMIN,EZUMAG,EZUANG,EZPMAG,EZPANG,PI,DTR,EPSO,
22. $ XG(4),YG(4),
23. $ X(NDIM),Y(NDIM),CLNQ(NDIM),XX(NDIM),YY(NDIM),
24. $ XI(MAXNX),YI(MAXNX),
25. $ XPLOT(NRPTS),Y1PLOT(NRPTS),Y2PLOT(NRPTS),Y3PLOT(NRPTS),
26. $ EXTIC,EYTIC,WXTIC,WYTIC,XMAX,XLNG,YLNG,WMIN,WMAX,EMIN,
27. $ ENLY
28. C
29. C INTEGER IROW(NDIM)
30. C
31. C CHARACTER*1 LABEL0/'?'/
32. C CHARACTER*4 ID(20)
33. C CHARACTER*5 LABEL1/'?'/, LABEL2/'____?'/,LABEL3/'____ '/
34. C CHARACTER*8 LABEL
35. C CHARACTER*36 LABEL
36. C
37. C COMMON/ONE/H12,H22,J1,J2,SO,ARGO,KA,KSO
38. C COMMON/LABELS/ID,LABEL,XLABEL
39. C COMMON/INPUT,FREQ,DMIN,DMAX,SIZEX,SIZEY,XO,YO,EXTIC,EYTIC,WXTIC,
40. $ WYTIC,XLNG,YLNG,EMIN,EMAX,WMIN,WMAX,XMAX,NUMX,NUMY,
41. $ IFLAG
42. C COMMON/PLDATA/XPLOT,Y1PLOT,Y2PLOT,Y3PLOT,NPTS
43. C
44. C DM - DIPOLE MOMENT IN AMPERE-METERS
45. C DMIN - MINIMUM RANGE (KM) FOR DISTANCE VARIATION
46. C DMAX - MAXIMUM RANGE (KM) FOR DISTANCE VARIATION
47. C DELD - INCREMENT (KM) FOR DISTANCE VARIATION
48. C YMAX - MAXIMUM OFF-AXIS VALUE (KM) FOR Y VARIATION
49. C DELY - INCREMENT (KM) FOR Y VARIATION
50. C IFLAG=1 Y VARIATION
51. C IFLAG=2 DIST VARIATION
52. C IGRID = 0 SQUARE OR RECTANGULAR DISTURBANCE
53. C IGRID = 1 CIRCULAR OR ELLIPTICAL DISTURBANCE
54. C XO,YO - COORDINATES (KM) AT CENTER OF DISTURBANCE
55. C YO IS ALSO INITIAL VALUE FOR Y VARIATION

```

```

56. C      NUMX,NUMY - THE DISTURBANCE IS DIVIDED INTO NUMX GRIDS IN THE
57. C      X DIRECTION AND NUMY GRIDS IN THE Y DIRECTION
58. C      SIZEX,SIZEY - DEFINES THE PHYSICAL SIZE OF THE DISTURBANCE - IT IS
59. C      SIZEX KM BY SIZEY KM
60. C      IPLOT=0  DON'T PLOT
61. C      IPLOT=1  PLOT
62. C      XLNG,YLNG - LENGTH (INCHES) OF X-AXIS AND Y-AXIS RESPECTIVELY
63. C      WMIN,WMAX - MINIMUM AND MAXIMUM (DB) FOR Y-AXIS OF WMAG PLOT
64. C      EMIN,EMAX - MINIMUM AND MAXIMUM (DB) FOR Y-AXIS OF EZ PLOT
65. C      EXTIC,EYTIC - UNITS PER TIC MARK ALONG X AND Y AXIS RESPECTIVELY
66. C      FOR EZ PLOTS
67. C      WXTIC,WYTIC - UNITS PER TIC MARK ALONG X AND Y AXIS RESPECTIVELY
68. C      FOR WMAG PLOTS
69. C
70. C      NAMELIST/DATUM/DM,DMIN,DMAX,DELD,YMAX,DELY,IFLAG,IGRID,
71. C      $      X0,Y0,NUMX,NUMY,SIZEX,SIZEY,IPLOT,XLNG,YLNG,
72. C      $      WMIN,WMAX,EMIN,EMAX,EXTIC,EYTIC,WXTIC,WYTIC
73. C
74. C      DATA IPLOT/0/
75. C      DATA PI/3.14159265358979E0/,DTR/.017453292E0/,EPS0/8.85434E-12/
76. C      DATA XLNG/5./,YLNG/6./,WMIN/-6./,WMAX/2./,EMIN/-6./,EMAX/2./
77. C      DATA EXTIC/200./,EYTIC/5./,SIZEX/1.E3/,SIZEY/1.E3/
78. C      DATA WXTIC/200./,WYTIC/1./
79. C      DATA DMIN/25.E0/,DMAX/1000.E0/,DELD/25.E0/
80. C      DATA YMAX/500.E0/,DELY/25.E0/,X0/0.E0/,Y0/0.E0/
81. C      DATA DM/6.75E6/
82. C      DATA IFLAG/2/,IGRID/0/
83. C      DATA CONST/(-.707106781186548E0,-.707106781186548E0)/
84. C
85. C
86. C      DEFINE CAPG2(ARG) = PI/(2.0E0* SIN(ARG/6371.0E0))
87. C
88. C      PRINT 915
89. C      READ(5,DATUM)
90. C      WRITE(6,DATUM)
91. C
92. C      NU = NUMX*NUMY
93. C      IF(NU .GT. NDIM)
94. C      $      THEN
95. C          PRINT 971
96. C          STOP
97. C      ENDIF
98. C      NPTS = 0
99. C      DIST = DMIN
100. C      YMID = Y0
101. C
102. C      SET UP DISTURBED REGION GRID
103. C      XINC = SIZEX/NUMX
104. C      HXINC = .5*XINC
105. C      YINC = SIZEY/NUMY
106. C      HYINC = .5*YINC
107. C
108. C      GRID ELEMENTS MUST BE SQUARE
109. C      IF(XINC .NE. YINC)
110. C      $      THEN
111. C          PRINT 976
112. C          STOP

```

```

1      113.      ENDIF
114.      YOVRX = SIZEY/SIZEX
115.      X1 = X0-0.5E0*(SIZEX-XINC)
116.      Y1 = Y0+0.5E0*(SIZEY-YINC)
117.      RADIUS = SQRT((XINC*YINC)/PI)
118.      XX(1) = X1
119.      DO 12 I=2,NUMX
1      120.      12 XX(I) = XX(I-1)+XINC
121.      YY(1) = Y1
122.      DO 13 J=2,NUMY
1      123.      13 YY(J) = YY(J-1)-YINC
124.      M = 0
125.      DO 15 J=1,NUMY
1      126.      DO 15 I=1,NUMX
2      127.      M = M+1
2      128.      X(M) = XX(I)
2      129.      Y(M) = YY(J)
2      130.      15 CONTINUE
2      131.      C
2      132.      C PRINT SCHEMATIC OF DISTURBED REGION GRID
133.      IF(NUMY .GT. 10) PRINT 915
134.      PRINT 920
135.      PRINT 930,(LABEL3,J=1,NUMX)
136.      DO 18 K=1,NUMY
1      137.      PRINT 910,LABEL0,(LABEL1,J=1,NUMX)
1      138.      PRINT 940,LABEL0,((K-1)*NUMX+J,LABEL0,J=1,NUMX)
1      139.      PRINT 910,LABEL0,(LABEL1,J=1,NUMX)
1      140.      PRINT 910,LABEL0,(LABEL2,J=1,NUMX)
1      141.      18 CONTINUE
1      142.      C
1      143.      C PRINT COORDINATES OF GRID
144.      PRINT 920
145.      N = 1
146.      WRITE(6,100) N,X(N),Y(N)
147.      WRITE(6,100) NUMX,X(NUMX),Y(NUMX)
148.      N = NU-NUX+1
149.      WRITE(6,100) N,X(N),Y(N)
150.      WRITE(6,100) NU,X(NU),Y(NU)
151.      C
152.      C READ GRID DATA
153.      C
154.      C MODE PARAMETERS ARE FROM USING NPUNCH=1 IN
155.      C THE WAVEGUID OR MODESRCH COMPUTER PROGRAMS
156.      READ 1000,ID
157.      PRINT 1001,ID
158.      C
159.      C AMBIENT
160.      READ 1010,FREQ,SIGMA,EPSP
161.      PRINT 1011,FREQ,SIGMA,EPSP
162.      OMEGA=6.28318530717959E3*FREQ
163.      WAVENO = .020958445E0*FREQ
164.      NGSQ = SIGMA/(IM*OMEGA*EPS0)+EPSP
165.      NGXTM = C SQRT(NGSQ)
166.      IF(DREAL(NGXTM) .LT. 0.0E0) NGXTM=-NGXTM
167.      EXO = 1.0E0/NGXTM
168.      ECGNST= .03248E6*DM*EXO*WAVENO**2/(5.0E3* SQRT(FREQ))
169.      N = 0

```

```

170.      PRINT 1009
171.      READ 1020,THETA0,TMP1
172.      THTAO = THETA0*DTR
173.      S0 = C SIN(THTAO)
174.      CSQ = (1.E0,0.E0)-S0**2
175.      C = C SQRT(CSQ)
176.      SQROOT = C SQRT(NGSQ-CSQ)
177.      XTRAO = -4.0*TMP1*S0
178.      PRINT 1021,N,THETA0,XTRAO
179.      KA = WAVENO*RADIUS
180.      KSO = WAVENO*S0
181.      ARGO = KSO*RADIUS
182.      CALL CBESJY(ARGO,1,BJ,BY,0,0)
183.      H12 = BJ- IM*BY
184.      J1 = BJ
185.      CALL CBESJY(ARGO,2,BJ,BY,0,0)
186.      H22 = BJ-IM*BY
187.      J2 = BJ
188.      C
189.      C      DISTURBED
190.      25  READ 1010,F
191.      IF(F.NE. 0.)
192.      $      THEN
193.      N = N+1
194.      IF(N.EQ. MAXNX)
195.      $      THEN
196.      PRINT 974
197.      STOP
198.      ENDIF
199.      READ 1020,THETAP,TMP1
200.      THTAP = THETAP*DTR
201.      SP = C SIN(THTAP)
202.*      XTRAP=-4.0*TMP1*SP
203.      PRINT 1021,N,THETAP,XTRAP
204.      SI(N) = SP
205.      XTRI(N) = XTRAP
206.      GO TO 25
207.      ELSE
208.      NMAX = N
209.      END IF
210.      C
211.      IF(NMAX.EQ. 1)
212.      $      THEN
213.      C      UNIFORM DISTURBANCE
214.      NMAX = 2
215.      SI(2) = SP
216.      XTRI(2) = XTRAP
217.      ENDIF
218.      C
219.      C      SET UP INTERPOLATION ARRAYS
220.      XDINC = 0.5E0*SIZEX/(NMAX-1)
221.      DO 33 N=1,NMAX
222.      XI(N) = XDINC*(N-1)
223.      33  YI(N) = YOVERX*XI(N)
224.      C
225.      C      FILL GRID OF SD AND XTRD
226.      IF(IGRID.EQ. 0)

```

```

227.      $ THEN
228.      C      SQUARE OR RECTANGLE
229.      C
230.      C      A RECTANGLE CAN ONLY BE UNIFORMLY DISTURBED
231.      C      A SQUARE CAN HAVE A NON-UNIFORM DISTURBANCE
232.      C      LABEL = 'SQUARE OR RECTANGULAR DISTURBANCE'
233.      DO 39 M=1,NU
234.      XM = ABS(X(M)-X0)
235.      YM = ABS(Y(M)-Y0)
236.      IF(XM .GT. .5E0*SIZEX .OR. YM .GT. .5E0*SIZEY)
237.      $      THEN
238.      SD(M) = S0
239.      XTRD(M) = XTRA0
240.      ELSE
241.      I = 1
242.      K = 1
243.      C
244.      35      IF(XM .LE. XI(I+1)) GO TO 37
245.      I = I+1
246.      GO TO 35
247.      37      IF(YM .LE. YI(K+1)) GO TO 38
248.      K = K+1
249.      GO TO 37
250.      38      IF(I .GT. K)
251.      $      THEN
252.      SLOPE = (XM-XI(I))/(XI(I+1)-XI(I))
253.      SD(M) = SI(I)+(SI(I+1)-SI(I))*SLOPE
254.      XTRD(M) = XTRI(I)+(XTRI(I+1)-XTRI(I))*SLOPE
255.      ELSE
256.      SLOPE = (YM-YI(K))/(YI(K+1)-YI(K))
257.      SD(M) = SI(K)+(SI(K+1)-SI(K))*SLOPE
258.      XTRD(M) = XTRI(K)+(XTRI(K+1)-XTRI(K))*SLOPE
259.      ENDIF
260.      ENDIF
261.      C
262.      39      CONTINUE
263.      C
264.      ELSE
265.      C      ELLIPSE OR CIRCLE
266.      LABEL = 'CIRCULAR OR ELLIPTICAL DISTURBANCE'
267.      AIMAX = XI(NMAX)
268.      DO 59 M=1,NU
269.      C      COORDS OF CENTER OF GRID RELATIVE TO CENTER OF DISTURBANCE
270.      XM = X(M)-X0
271.      YM = Y(M)-Y0
272.      C      COORDS OF CORNERS OF GRID
273.      XG(1) = XM-HXINC
274.      XG(2) = XM+HXINC
275.      XG(3) = XG(1)
276.      XG(4) = XG(2)
277.      YG(1) = YM-HYINC
278.      YG(2) = YM+HYINC
279.      YG(3) = YG(1)
280.      YG(4) = YG(2)
281.      RGMAX = -1.0E6
282.      RGMIN = 1.0E6
283.      DO 45 I=1,4

```

```

2      284.  C      RANGE OF EACH CORNER FROM CENTER OF DISTURBANCE
3      285.      RG = SQRT(XG(1)**2+(YG(1)/YOVERX)**2)
3      286.      RGMAX = AMAX1(RGMAX, RG)
3      287.  45      RGMIN = AMIN1(RGMIN, RG)
2      288.      IF(RGMIN .GE. AIMAX)
2      289.          $      THEN
2      290.  C      GRID IS COMPLETELY OUTSIDE OF DISTURBANCE
3      291.      SD(M) = S0
3      292.      XTRD(M) = XTRA0
3      293.      ELSE
3      294.          $      IF(RGMAX .LE. AIMAX)
3      295.              THEN
3      296.  C      GRID IS COMPLETELY INSIDE OF DISTURBANCE
4      297.      I = 1
4      298.      AI = SQRT(XM**2+(YM/YOVERX)**2)
4      299.  50      IF(AI .LE. XI(I+1)) GO TO 51
4      300.      I = I+1
4      301.      GO TO 50
4      302.  51      SLOPE = (AI-XI(I))/(XI(I+1)-XI(I))
4      303.      SD(M) = SI(I)+(SI(I+1)-SI(I))*SLOPE
4      304.      XTRD(M) = XTRI(I)+(XTRI(I+1)-XTRI(I))*SLOPE
4      305.      ELSE
4      306.  C      GRID IS ON BORDER OF THE DISTURBANCE
4      307.  C      DIVIDE GRID INTO 16 SUBSQUARES
4      308.      DELTAX = XINC/8.
4      309.      DELTAY = YINC/8.
4      310.      XG(1) = (XM-DELTAX*3.)*2
4      311.      XG(2) = (XM-DELTAX)*2
4      312.      XG(3) = (XM+DELTAX)*2
4      313.      XG(4) = (XM+DELTAX*3.)*2
4      314.      YG(1) = ((YM+DELTAY*3.)/YOVERX)*2
4      315.      YG(2) = ((YM+DELTAY)/YOVERX)*2
4      316.      YG(3) = ((YM-DELTAY)/YOVERX)*2
4      317.      YG(4) = ((YM-DELTAY*3.)/YOVERX)*2
4      318.  C      COUNT NUMBER OF SUBSQS WITHIN DISTURBANCE
4      319.      N = 0
4      320.      DO 55 I=1,4
5      321.      XGSQ = XG(I)
5      322.      DO 55 J=1,4
6      323.      RG = SQRT(XGSQ+YG(J))
6      324.  55      IF(RG .LE. AIMAX) N=N+1
4      325.      SLOPE = N/16.
4      326.      SD(M) = S0+(SI(NMAX)-S0)*SLOPE
4      327.      XTRD(M) = XTRA0+(XTRI(NMAX)-XTRA0)*SLOPE
4      328.      ENDIF
3      329.      ENDIF
2      330.  59      CONTINUE
1      331.      ENDIF
1      332.  C
1      333.  C      SET UP A
3      334.      DO 55 M=1,NU
1      335.      DO 65 N=1,NU
2      336.  65      A(M,N) = CAPA(SD(N),SQRT((X(M)-X(N))**2+(Y(M)-Y(N))**2))
2      337.  C
3      338.  70      MGRID = 0
3      339.      DO 79 M= 1,NU
1      340.      NGRID = 0

```

```

1      341.      XM = X(M)
1      342.      YM = Y(M)
1      343.      IF(XM+ HXINC .LT. 0.0E0 .OR. XM- HXINC .GE. 0.0E0 .OR.
1      344.      $   YM+ HYINC .LT. 0.0E0 .OR. YM- HYINC .GE. 0.0E0) GO TO 75
1      345.      C   XMTR IS INSIDE GRID
1      346.      C   GRID POINT IS DISTURBED
1      347.      XG(1) = XM-.25*XINC
1      348.      XG(3) = XG(1)
1      349.      XG(2) = XM+.25*XINC
1      350.      XG(4) = XG(2)
1      351.      YG(1) = YM+.25*YINC
1      352.      YG(2) = YG(1)
1      353.      YG(3) = YM-.25*YINC
1      354.      YG(4) = YG(3)
1      355.      MGRID = M
1      356.      PRINT 955,M
1      357.      NQUAD = 0
1      358.      SUM = 0.0E0
1      359.      71  NQUAD = NQUAD+1
1      360.      IF(XG(NQUAD)+.125*XINC .GE. 0.0E0 .AND.
1      361.      $   XG(NQUAD)-.125*XINC .LT. 0.0E0 .AND.
1      362.      $   YG(NQUAD)+.125*YINC .GE. 0.0E0 .AND.
1      363.      $   YG(NQUAD)-.125*YINC .LT. 0.0E0) GO TO 71
1      364.      NGRID = NGRID+1
1      365.      XM = XG(NQUAD)
1      366.      YM = YG(NQUAD)
1      367.      75  RHOMN = SQRT(XM**2+YM**2)
1      368.      ARGU = KSO*RHOMN
1      369.      CALL CBESJY(ARGU,1,BJ,BY,0,0)
1      370.      H12 = BJ-IM*BY
1      371.      IF(XM .EQ. 0.0E0) XM=1.0E-6
1      372.      EZ0(M) = C SQRT(ARGU*CAPG2(RHOMN))*CONST*H12*XM/RHOMN
1      373.      IF(NGRID .EQ. 0) GO TO 78
1      374.      SUM = SUM+EZ0(M)
1      375.      IF(NQUAD .LT. 4) GO TO 71
1      376.      EZ0(M) = SUM/NGRID
1      377.      78  IF(C ABS(EZ0(M)) .LE. 1.0E-6) EZ0(M)=1.0E-21
1      378.      79  CONTINUE
1      379.      C
1      380.      C   PRINT TABLE OF EZ0
1      381.      WRITE (6,110) YMID
1      382.      WRITE (6,113)
1      383.      DO 81 I=1,NUMY
1      384.      WRITE(6,112) (C ABS(EZ0(NUMX*(I-1)+J)),J=1,NUMX)
1      385.      81  CONTINUE
1      386.      C
1      387.      C   SOLVE FOR SCATTERED FIELDS
1      388.      CALL CLINEQ(A,EZ0,EZS,IROW,CLNQ,NU,NDIM,NPTS,ERR)
1      389.      C
1      390.      C   PRINT TABLE OF EZS
1      391.      WRITE (6,111)
1      392.      DO 83 I=1,NUMY
1      393.      WRITE(6,112) (C ABS(EZS(NUMX*(I-1)+J)),J=1,NUMX)
1      394.      83  CONTINUE
1      395.      C
1      396.      DO 85 M=1,NU
1      397.      RATIO = EZS(M)/EZ0(M)

```

```

1      398.      IF(MGRID .EQ. M) RATIO=1.0
1      399.      WI(M) = C LOG(RATIO)
1      400.      85      CONTINUE
1      401.      C
1      402.      C      PRINT TABLE OF WI
1      403.      WRITE(6,102)
1      404.      DO 87 I=1,NUMY
1      405.      WRITE(6,103) (REAL(WI(NUMX*(I-1)+J))*8.686,J=1,NUMX)
1      406.      87      CONTINUE
1      407.      C
1      408.      WRITE (6,950)
1      409.      DIST = DMIN
1      410.      90      NPTS = NPTS+1
1      411.      IF(NPTS .GT. NRPTS)
1      412.      $      THEN
1      413.      $          PRINT 973
1      414.      $          STOP
1      415.      $      ENDIF
1      416.      C
1      417.      ARGU = KSO*DIST
1      418.      CALL CBESJY(ARGU,1,BJ,BY,0,0)
1      419.      H12 = BJ-IM*BY
1      420.      EZU = C SQRT(ARGU*CAPG2(DIST))*CONST*H12
1      421.      IF(XX(1)-HXINC .GE. DIST .OR. XX(NUMX)+HXINC .LE. DIST .OR.
1      422.      $      YY(1)+HYINC .LE. 0.E0 .OR. YY(NUMY)-HYINC .GE. 0.E0)
1      423.      $      THEN
1      424.      C          RCVR IS OUTSIDE OF DISTURBED AREA
1      425.      XTRA2 = XTRA0
1      426.      SUM = (0.0E0,0.0E0)
1      427.      DO 95 N=1,NU
1      428.      RHOMN = SQRT((DIST-X(N))**2+Y(N)**2)
1      429.      SUM = SUM+CAPA(SD(N),RHOMN)*EZS(N)
1      430.      95      CONTINUE
1      431.      EZ = EZU-SUM
1      432.      RATIO = EZ/EZU
1      433.      WMAG = 20.0E0*ALOG10(C ABS(RATIO))
1      434.      WANG = C ANG(RATIO)
1      435.      ELSE
1      436.      C          RCVR IS IN DISTURBED AREA
1      437.      I = 1
1      438.      DO 96 J=1,NUMX
1      439.      IF(XX(J)-HXINC .LT. DIST .AND. DIST .LE. XX(J)+HXINC)
1      440.      $      GO TO 97
1      441.      I = I+1
1      442.      96      CONTINUE
1      443.      97      K = I
1      444.      DO 98 J=1,NUMY
1      445.      IF(YY(J)-HYINC .LT. 0.E0 .AND. 0.E0 .LE. YY(J)+HYINC)
1      446.      $      GO TO 99
1      447.      K = K+1
1      448.      98      CONTINUE
1      449.      99      M = (K-1)*NUMX+I
1      450.      XTRA2 = XTRD(M)
1      451.      EZ = EZU
1      452.      IF(M .EQ. MGRID) GO TO 130
1      453.      IF(I .GT. 1) GO TO 120
1      454.      N1 = M

```

```

1      455.      N2 = M+1
1      456.      IF(K .GT. 1) GO TO 106
1      457.      N3 = N1+NUMX
105    458.      N4 = N3+1
1      459.      GO TO 125
1      460.      IF(K .EQ. NUMY) GO TO 108
1      461.      IF(YY(K) .GE. 0.) GO TO 109
1      462.      N3 = N1-NUMX
1      463.      N4 = N3+1
1      464.      GO TO 125
1      465.      N3 = N1+NUMX
109    466.      N4 = N3+1
1      467.      GO TO 125
1      468.      IF(I .LT. NUMX) GO TO 122
1      469.      N1 = M-1
1      470.      N2 = M
1      471.      IF(K .EQ. 1) GO TO 105
1      472.      IF(K .EQ. NUMY) GO TO 108
1      473.      GO TO 107
1      474.      IF(XX(I) .LE. DIST) GO TO 123
1      475.      N1 = M-1
1      476.      N2 = M
1      477.      GO TO 121
1      478.      N1 = M
123    479.      N2 = M+1
1      480.      GO TO 121
1      481.      SLOPE = -Y(N1)/(Y(N3)-Y(N1))
125    482.      W1 = WI(N1)+(WI(N3)-WI(N1))*SLOPE
1      483.      W2 = WI(N2)+(WI(N4)-WI(N2))*SLOPE
1      484.      IF(1 .EQ. NUMX .AND. DIST .GT. X(N2) .OR.
1      485.      I .EQ. 1 .AND. DIST .LT. X(N1))
1      486.      THEN
2      487.      IF(I .EQ. 1)
2      488.      THEN
3      489.      DST = X0-.5*SIZEX
3      490.      DELTAX = HXINC
3      491.      W2 = W1
3      492.      N2 = N1
3      493.      ELSE
3      494.      DST = X0+.5*SIZEX
3      495.      DELTAX = -HXINC
3      496.      ENDIF
2      497.      ARGU = KSO*DST
2      498.      CALL CBESJY(ARGU,1,BJ,BY,0,0)
2      499.      H12 = BJ-IM*BY
2      500.      EZ1 = C SQRT(ARGU+CAPG2(DST))*CONST*H12
2      501.      SUM = (0.0E0,0.0E0)
2      502.      DO 126 N=1,NU
3      503.      RHOMN = SQRT((DST -X(N))**2+Y(N)**2)
3      504.      SUM = SUM+CAPA(SD(N),RHOMN)*EZN(N)
3      505.      CONTINUE
2      506.      W1 = CLOG((1.0,0.0)-SUM/EZ1)
2      507.      RATIO = W1+(W2-W1)*(DIST-DST)/DELTAX
2      508.      ELSE
2      509.      RATIO = W1+(W2-W1)*((DIST-X(N1))/XINC)
2      510.      ENDIF
1      511.      WMAG = REAL(RATIO)*8.686

```

```

1      512.          WANG = AIMAG(RATIO)
1      513.          EZ = C EXP(RATIO)*EZU
1      514.          ENDIF
1      515.      C
1      516.      C
1      517.      130  IF(MGRID .EQ. 0)
1      518.      $    THEN
1      519.      C          XMTR IS OUTSIDE OF DISTURBED AREA
1      520.          XTRA1 = XTRA0
1      521.      ELSE
1      522.      C          XMTR IS IN DISTURBED AREA
1      523.          XTRA1 = XTRD(MGRID)
1      524.      ENDIF
1      525.      C
1      526.          EZUABS = ECONST*EZU*XTRA0
1      527.          EZPABS = ECONST*EZ*C SORT(XTRA1*XTRA2)
1      528.          RATIO = EZPABS/EZUABS
1      529.          EZREL = 20.0E0*ALOG10(C ABS(RATIO))
1      530.          EZANG = C ANG(RATIO)
1      531.          EZUMAG = 20.0E0*ALOG10(C ABS(EZUABS))
1      532.          EZUANG = C ANG(EZUABS)
1      533.          EZPMAG = 20.0E0*ALOG10(C ABS(EZPABS))
1      534.          EZPANG = C ANG(EZPABS)
1      535.          WRITE (6,960) YMID,DIST,WMAG,WANG,EZREL,EZANG,
1      536.          $          EZUMAG,EZUANG,EZPMAG,EZPANG
1      537.          Y1PLOT(NPTS) = WMAG
1      538.          Y2PLOT(NPTS) = EZUMAG
1      539.          Y3PLOT(NPTS) = EZPMAG
1      540.          IF(IFLAG .EQ. 2) GO TO 140
1      541.      C
1      542.      C      Y VARIATION
1      543.          DO 131 N = 1,NU
1      544.      131  Y(N) = Y(N)+DELY
1      545.          DO 132 J=1,NUMY
1      546.      132  YY(J) = YY(J)+DELY
1      547.          XPLOT(NPTS) = YMID
1      548.          XLABEL = ' Y(KM) '
1      549.          YMID = YMID+DELY
1      550.          IF(YMID .LE. YMAX) GO TO 70
1      551.          XMAX = YMAX
1      552.          IF(IPLLOT .EQ. 1) GO TO 800
1      553.          STOP
1      554.      C
1      555.      C      DISTANCE VARIATION
1      556.      140  XPLOT(NPTS) = DIST
1      557.          XLABEL = ' X(KM) '
1      558.          DIST = DIST + DELO
1      559.          IF(DIST .LE. DMAX) GO TO 90
1      560.          XMAX = DMAX
1      561.          IF(IPLLOT .EQ. 1) GO TO 800
1      562.          STOP
1      563.      C
1      564.      C      PLOTTING
1      565.      800  CALL DBPLOT
1      566.      C
1      567.      100  FORMAT(' COORDINATES AT CENTER OF MESH NUMBER ',I3,' ARE: X=',
1      568.      $      F8.2,' Y=',F8.2)

```

```

569. 102  FORMAT(/,10X,'WI')
570. 103  FORMAT(1X,13F10.4)
571. 110  FORMAT(1H0,'YMID = ',F12.2)
572. 111  FORMAT(/,10X,'EVS')
573. 112  FORMAT((1X,(1P13E10.2)))
574. 113  FORMAT(/,10X,'EZO')
575. 910  FORMAT(20X,A1,13A5)
576. 915  FORMAT('1')
577. 920  FORMAT('0')
578. 930  FORMAT(21X,13A5)
579. 940  FORMAT (20X,A1,13(I3,1X,A1))
580. 950  FORMAT(/,4X,'YMID',5X,'DIST',6X,' WMAG ',8X,' WANG ',8X,' EZREL',
581. $ 8X,' EZANG',8X,'EZUMAG',8X,'EZUANG',8X,'EZPMAG',8X,'EZPANG')
582. 955  FORMAT('0XMTR IS INSIDE GRID ',I3)
583. 960  FORMAT(2(2X,F7.1),8(2X,1P12.5))
584. 971  FORMAT(' NU = NUMX*NUMY IS GREATER THAN PARAMETER VARIABLE NDM')
585. 972  FORMAT(' NMAX DOES NOT EQUAL NU OR 1')
586. 973  FORMAT(' NUMBER OF POINTS PLOTTED IS GREATER THAN PARAMETER VARIAB
587. $LE NRPTS')
588. 974  FORMAT(' N IS GREATER THAN PARAMETER VARIABLE MAXNX')
589. 976  FORMAT(' XINC MUST EQUAL YINC')
590. 1000  FORMAT(20A4)
591. 1001  FORMAT('1',20A4)
592. 1009  FORMAT(2X,'GRID',6X,'THETA',25X,'XTRA')
593. 1010  FORMAT(10X,E8.0,34X,E10.0,2X,E5.0)
594. 1011  FORMAT(' FREQ = ',E10.3,' SIGMA = ',E10.3,' EPSR=',F7.2)
595. 1020  FORMAT(1X,2I9.0,1X,2E15.0//)
596. 1021  FORMAT(1X,I3,2F10.5,2X,1P2E18.9)
597.      END

```

END FTN 2678 IBANK 22972 DBANK 2068 COMMON

```

1      SUBROUTINE DBPLOT
2      PARAMETER NRPTS=500
3      CHARACTER*8 XLABEL
4      CHARACTER*36 LABEL
5      CHARACTER*4 ID(20)
6      DIMENSION XPLOT(NRPTS),Y1PLOT(NRPTS),Y2PLOT(NRPTS),Y3PLOT(NRPTS)
7      COMMON/LABELS/ID,LABEL,XLABEL
8      COMMON/INPUT/FREQ,DMIN,DMAX,SIZEX,SIZEY,X0,Y0,EXTIC,EYTIC,WYTIC,
9      WYTIC,XLNG,YLNG,EMIN,EMAX,WMIN,WMAX,XMAX,NUMX,NUMY,
10     $      IFLAG
11     $ COMMON/PLDATA/XPLOT,Y1PLOT,Y2PLOT,Y3PLOT,NPTS
12     CALL BGNPL(1)
13     CALL PHYSOR(2.0,2.0)
14     CALL TITLE(' ',1,XLABEL,8,'WMAG(DB)',8,XLNG,YLNG)
15     CALL INTAXS
16     CALL YAXANG(0.0)
17     CALL GRAF(0.,WYTIC,XMAX,WMIN,WYTIC,WMAX)
18     CALL CURVE(XPLOT,Y1PLOT,NPTS,0)
19     CALL MESSAG(ID,80,0.0,-0.8)
20     CALL MESSAG(LABEL,36,0.0,-1.0)
21     CALL MESSAG('FREQ = ',7,0.0,-1.2)
22     CALL REALNO( FREQ,3,0.7,-1.2)
23     IF(IFLAG.EQ. 1) CALL MESSAG('DMIN = ',6,2.0,-1.2)
24     IF(IFLAG.EQ. 1) CALL REALNO( DMIN,1,2.7,-1.2)
25     CALL MESSAG('SIZEX= ',X0=          NUMX= ',32,0.0,-1.4)
26     CALL REALNO( SIZEX,1,0.7,-1.4)
27     CALL REALNO( X0,1,2.0,-1.4)
28     CALL INTNO(NUMX,3,7,-1.4)
29     CALL MESSAG('SIZEY= ',Y0=          NUMY= ',32,0.0,-1.6)
30     CALL REALNO( SIZEY,1,0.7,-1.6)
31     CALL REALNO( Y0,1,2.0,-1.6)
32     CALL INTNO(NUMY,3,7,-1.6)
33     CALL ENDPL(1)
34     CALL BGNPL(2)
35     CALL PHYSOR(2.0,2.0)
36     CALL TITLE(' ',1,XLABEL,8,'DB ABOVE 1 MICROVOLT/METER',26,
37     $ XLNG,YLNG)
38     CALL INTAXS
39     CALL YAXANG(0.0)
40     CALL GRAF(0.,EXTIC,XMAX,EMIN,EYTIC,EMAX)
41     CALL CURVE(XPLOT,Y2PLOT,NPTS,0)
42     CALL DASH
43     CALL CURVE(XPLOT,Y3PLOT,NPTS,0)
44     CALL RESET('DASH')
45     CALL STRIPT(XLNG-2.0,YLNG)
46     CALL CONNPT(XLNG-0.9,YLNG)
47     CALL MESSAG('          EZUMAG',16,XLNG-2.0,YLNG)
48     CALL MESSAG('----- EZPMAG',16,XLNG-2.0,YLNG-0.3)
49     CALL MESSAG(ID,80,0.0,-0.8)
50     CALL MESSAG(LABEL,36,0.0,-1.0)
51     CALL MESSAG('FREQ = ',7,0.0,-1.2)
52     CALL REALNO( FREQ,3,0.7,-1.2)
53     IF(IFLAG.EQ. 1) CALL MESSAG('DMIN = ',6,2.0,-1.2)
54     IF(IFLAG.EQ. 1) CALL REALNO( DMIN,1,2.7,-1.2)

```

55	CALL MESSAG('SIZEX=	X0=	NUMX= ' ,32,0.0,-1.4)
56	CALL REALNO( SIZEX,1,0.7,-1.4)		
57	CALL REALNO( X0,1,2.0,-1.4)		
58	CALL INTNO(NUMX,3.7,-1.4)		
59	CALL MESSAG('SIZEY=	Y0=	NUMY= ' ,32,0.0,-1.6)
60	CALL REALNO( SIZEY,1,0.7,-1.6)		
61	CALL REALNO( Y0,1,2.0,-1.6)		
62	CALL INTNO(NUMY,3.7,-1.6)		
63	CALL ENDPL(2)		
64	RETURN		
65	END		

```

1      SUBROUTINE CBESJY(Z,K,BJ,BY,KIND,NPRINT)
2      IMPLICIT COMPLEX (A-H,O-Z)
3      REAL  DGMSUM,DG1,DG2,PI/3.14159265358979E0/,RRT,
4      $      EULER/0.577215664901533E0/
5
6      C THIS SUBROUTINE CALCULATES BESSEL FUNCTIONS OF THE FIRST KIND(JN) AND
7      C OF THE SECOND KIND(YN). N IS THE ORDER AND IS ALLOWED TO BE ANY
8      C POSITIVE INTEGER.
9      C THE ARGUMENT MUST BE DECLARED COMPLEX IN THE CALLING ROUTINE.
10     C IF A REAL ARGUMENT IS DESIRED JUST SET THE IMAGINARY PART TO ZERO.
11     C FOR THE ARGUMENT Z=RHO*C EXP(I*PHI) THE EMPLOYED EQUATIONS ARE VALID
12     C AS FOLLOWS:
13     C IF 0<RHO<13 THEN PHI=ANY VALUE
14     C IF RHO=13 OR 13<RHO<INFINITY THEN PHI=PI OR -PI<PHI<PI
15
16     C FOR RHO=0 J0 AND J1 ARE SET TO THEIR CORRECT VALUES.
17     C HOWEVER, Y0 AND Y1 ARE NOT CALCULATED SINCE THEY APPROACH INFINITY
18     C IN THE REAL AND/OR IMAGINARY PART, THEREFORE AN ERROR MESSAGE IS
19     C PRINTED.
20
21     C
22     C Z IS THE ARGUMENT.
23     C K IS THE ORDER.
24     C BJ IS THE BESSEL FUNCTION OF THE FIRST KIND.
25     C BY IS THE BESSEL FUNCTION OF THE SECOND KIND.
26     C KIND=1 CAUSES CALCULATION OF THE BESSEL FUNCTION OF THE FIRST KIND
27     C ONLY.
28     C ANY OTHER VALUE OF KIND CAUSES CALCULATIONS TO BE DONE FOR BESSEL
29     C FUNCTIONS OFF BOTH THE FIRST AND SECOND KIND.
30     C NPRINT=0 CAUSES NO DEBUG PRINTOUT.
31     C NPRINT=1 CAUSES DEBUG PRINTOUT.
32
33     C THE CALLING STATEMENT MUST HAVE DECLARED THE PARAMETERS CORRESPONDING
34     C TO Z, BJ, AND BY AS COMPLEX .
35
36     C
37     IF(C ABS(Z) .NE. 0.E0) GO TO 7
38     BJ=(0.0E0,0.0E0)
39     IF(K .EQ. 0) BJ=(1.0E0,0.0E0)
40     IF(KIND .NE. 1 .AND. K .EQ. 0) PRINT 400
41     400 FORMAT(1H0,'*** Y NOT CALCULATED FOR ARGUMENT OF MAGNITUDE 0'//)
42     RETURN
43     7 IF(C ABS(Z) .LT. 13.E0) GO TO 10
44
45     C
46     C ASYMPTOTIC EXPANSION
47     C
48     RHO=B.*Z
49     MU=4*K**2
50     RT=C SQRT(2./(PI*Z))
51     RRT=RT
52     IF(RRT .LT. 0.) RT=-RT
53     P=0.
54     C DO LOOP FOR CALCULATING P

```

```

55      DO 1 N=1,30
56      M=N-1
57      MM=2*M
58      IF(N.EQ. 1) GO TO 2
59      TERM=(-1)*(MU-(2*MM-3)**2)*(MU-(2*MM-1)**2)/(MM*(MM-1)*RHO**2)*
60      $TERM
61      IF(NPRINT.EQ. 1) PRINT 100,TERM
62      100 FORMAT(1X,'TERM=',2E30.15)
63      P=P+TERM
64      IF(C ABS(TERM) .GE. C ABS(TERMS) .OR. C ABS(TERM) .LE. 1.E-17) GO
65      $TO 3
66      TERMS=TERM
67      GO TO 1
68      2 TERM=1.E0
69      P=TERM
70      IF(NPRINT.EQ. 1) PRINT 100,TERM
71      TERMS=TERM
72      1 CONTINUE
73      3 CONTINUE
74      IF(NPRINT.EQ. 1) PRINT 200,P
75      200 FORMAT(1H0,'P=',2E30.15)
76      Q=0.
77      C DO LOOP FOR CALCULATING Q
78      DO 4 N=1,30
79      M=N-1
80      MM=2*M
81      MMM=2*M+1
82      IF(N.EQ. 1) GO TO 5
83      TERM=(-1)*(MU-(2*MM-1)**2)*(MU-(2*MM+1)**2)/(MMM*(MMM-1)*RHO**2)*
84      $TERM
85      IF(NPRINT.EQ. 1) PRINT 100,TERM
86      Q=Q+TERM
87      IF(C ABS(TERM) .GE. C ABS(TERMS) .OR. C ABS(TERM) .LE. 1.E-17) GO
88      $TO 6
89      TERMS=TERM
90      GO TO 4
91      5 TERM=(MU-1)/RHO
92      Q=TERM
93      IF(NPRINT.EQ. 1) PRINT 100,TERM
94      TERMS=TERM
95      4 CONTINUE
96      6 CONTINUE
97      IF(NPRINT.EQ. 1) PRINT 300,Q
98      300 FORMAT(1H0,'Q=',2E30.15)
99      BJ=RT*C COS(Z-K*PI/2.-PI/4.)*P-RT*C SIN(Z-K*PI/2.-PI/4.)*Q
100     IF(KIND.EQ. 1) GO TO 8
101     BY=RT*C SIN(Z-K*PI/2.-PI/4.)*P+RT*C COS(Z-K*PI/2.-PI/4.)*Q
102     8 RETURN
103
104     C
105     C POWER SERIES EXPANSION
106     C
107     10 NTERMS=35
108     KFAC=1
109     IF(K.LE. 1) GO TO 30
110     DO 20 N=2,K
111     20 KFAC=KFAC*N

```

```

112      30 TERM=(Z/2.)**K/KFAC
113      BJ=TERM
114      IF(KIND .EQ. 1) GO TO 91
115      DG1=0.
116      DG2=0.
117      IF(K .EQ. 0) GO TO 80
118      DO 60 N=1,K
119      60 DG2=DG2+1./N
120      80 TSUM3=-TERM*DG2
121      SUMT3=TSUM3
122      91 DO 40 M=1,NTERMS
123      TERM=TERM*(Z/2.)**2*(-1)/((K+M)*M)
124      BJ=BJ+TERM
125      IF(KIND .EQ. 1) GO TO 92
126      DG1=DG1+1.E0/M
127      DG2=DG2+1.E0/(M+K)
128      DGMSUM=DG1+DG2
129      TSUM3=-TERM*DGMSUM
130      SUMT3=SUMT3+TSUM3
131      92 IF(C ABS(TERM) .LE. 1.E-17) GO TO 50
132      40 CONTINUE
133      50 IF(KIND .EQ. 1) GO TO 93
134      TERM3=SUMT3/PI
135      TERM1=(2./PI)*BJ*(EULER+C LOG(Z/2.))
136      SUMT2=(0.,0.)
137      IF(K .EQ. 0) GO TO 120
138      KM1FAC=KFAC/K
139      TSUM2=KM1FAC*(Z/2.)**(-K)
140      SUMT2=TSUM2
141      IF(K .EQ. 1) GO TO 120
142      KM1=K-1
143      DO 130 M=1,KM1
144      KMM=K-M
145      TSUM2=TSUM2/(KMM*M)*(Z/2.)**2
146      130 SUMT2=SUMT2+TSUM2
147      120 TERM2=-SUMT2/PI
148      BY=TERM1+TERM2+TERM3
149      93 RETURN
150      END

```

```

1      SUBROUTINE CLIN EQ (A,B,X,IROW,Q,N,NDIM,IFLAG,ERR)
2      C
3      C CLIN EQ USES L-U DECOMPOSITION TO
4      C FIND THE TRIANGULAR MATRICES L, U
5      C SUCH THAT  $L * U = A$ . L AND U ARE
6      C STORED IN A. THIS FORM IS USED WITH
7      C BACK-SUBSTITUTION TO FIND THE SOLN
8      C X OF  $A * X = L * U * X = B$ .
9      C N IS THE NUMBER OF EQUATIONS AND
10     C N DIM IS THE DIMENSION OF ALL ARRAYS
11     C IN THE PARAMETER LIST.
12     C
13     C IF IFLAG = 0, L, U, AND X ARE
14     C COMPUTED.
15     C IF IFLAG IS NON-ZERO, IT IS ASSUMED
16     C THAT L AND U HAVE BEEN COMPUTED IN
17     C A PREVIOUS CALL AND ARE STILL STORED
18     C IN A. THUS ONLY X IS COMPUTED.
19     C ERR IS THE ESTIMATED RELATIVE
20     C ERROR OF THE SOLUTION VECTOR.
21     C
22     C COMPLEX      A, B, X, T
23     C REAL      ERR
24     C DIMENSION A(NDIM,NDIM),B(NDIM),X(NDIM)
25     C DIMENSION IROW(NDIM),Q(NDIM)
26     C DATA EPS /1.0E-15/
27     C
28     C
29     C IF (N.GT.NDIM) GO TO 900
30     C IF (IFLAG.NE.0) GO TO 600
31     C DO 050 I = 1,N
32     C   Q(I) = 0.0
33     C   DO 040 J = 1,N
34     C     QQ = C ABS (A(I,J))
35     C 040 IF (Q(I).LT.QQ) Q(I) = QQ
36     C   IF (Q(I).EQ.0.0) GO TO 901
37     C 050 CONTINUE
38     C   ERR = EPS
39     C   PPIV = 0.0
40     C   DO 100 I = 1,N
41     C     100 IROW(I) = I
42     C
43     C   DO 500 L = 1,N
44     C     PIVOT = 0.0
45     C     K = L - 1
46     C     DO 240 I = L,N
47     C       IF (K.LT.1) GO TO 230
48     C       DO 220 J = 1,K
49     C         220 A(I,L) = A(I,L) - A(J,L) * A(I,J)
50     C       230 F = C ABS (A(I,L)) / Q(I)
51     C       IF (PIVOT.GT.F) GO TO 240
52     C       PIVOT = F
53     C       NPIVOT = I
54     C 240 CONTINUE

```

```

55      IF (PIVOT.EQ.0.0) GO TO 901
56      IF (PPIV.LE.PIVOT) GO TO 250
57      ERR = ERR * PPIV / PIVOT
58      IF (ERR.GE.1.0) GO TO 901
59      250 PPIV = PIVOT
60      IF (NPIVOT.EQ.L) GO TO 280
61      Q(NPIVOT) = Q(L)
62      J = IROW(L)
63      IROW(L) = IROW(NPIVOT)
64      IROW(NPIVOT) = J
65      DO 260 I = 1,N
66      T = A(L,I)
67      A(L,I) = A(NPIVOT,I)
68      A(NPIVOT,I) = T
69      260 CONTINUE
70      280 IF (L.EQ.N) GO TO 500
71      T = (1.0E0,0.0E0) / A(L,L)
72      K = L + 1
73      M = L - 1
74      DO 450 I = K,N
75      IF (M.L.T.1) GO TO 400
76      DO 350 J = 1,M
77      350 A(L,I) = A(L,I) - A(L,J) * A(J,I)
78      400 A(L,I) = T * A(L,I)
79      450 CONTINUE
80      500 CONTINUE
81      IF (ERR.GT.1.0E-5) PRINT 998, ERR
82      C
83      C
84      600 DO 620 I = 2,N
85      620 X(I) = (0.0E0,0.0E0)
86      J = IROW(1)
87      X(1) = B(J) / A(1,1)
88      DO 700 I = 2,N
89      J = IROW(I)
90      K = I - 1
91      DO 650 L = 1,K
92      650 X(I) = X(I) + A(I,L) * X(L)
93      X(I) = (B(J) - X(I)) / A(I,I)
94      700 CONTINUE
95      K = N - 1
96      DO 800 I = 1,K
97      J = N - I
98      M = J + 1
99      DO 800 L = M,N
100     X(J) = X(J) - X(L) * A(J,L)
101     800 CONTINUE
102     RETURN
103     C
104     900 PRINT 999
105     ERR = 1.0
106     RETURN
107     901 PRINT 997
108     ERR = 1.0
109     RETURN
110     997 FORMAT ('1ERROR IN CLIN EQ, MATRIX IS SINGULAR')
111     998 FORMAT (' CAUTION-',

```

```
112      $ ' CLIN EQ HAS DECOMPOSED AN ILL-CONDITIONED MATRIX.',/.  
113      $ ' RESULTS WILL HAVE RELATIVE ERROR =' ,E11.2)  
114 999 FORMAT ('1ERROR IN CLIN EQ, MATRIX SIZE GREATER THAN NDIM')  
115      END
```

```

1      FUNCTION C ANG(ARG)
2      IMPLICIT REAL (A-H,O-Z)
3      COMPLEX ARG,MINUSI/(0.0E0,-1.0E0)/
4      ARGR=ARG
5      ARG1=MINUSI*ARG
6      C ANG= ATAN2(ARG1,ARGR)
7      IF(ARG1 .LT. 0.) C ANG=C ANG+6.2831853072E00
8      RETURN
9      END

```

```

1      COMPLEX FUNCTION CAPA(SP,RHO)
2      IMPLICIT COMPLEX (A-H,O-Z)
3      COMPLEX IM/(0.E0,1.E0)/,J1,J2
4      COMPLEX KSO
5      REAL KA,RHO
6      COMMON/ONE/H12,H22,J1,J2,S0,ARG0,KA,KSO
7      DEFINE CAPG1(ARG) = SQRT(ARG/(6371.0E0* SIN(ARG/6371.0E0)))
8      ARGP = KA*SP
9      TERM1 = (0.0E0,0.785398163397448E0)*((SP/S0)**2-1.0E0)
10     TERM2 = 2.0E0*ARG0*(1.0E0-.25E0*ARGP**2)
11     IF(RHO .EQ. 0.0) THEN
12         CAPA = (SP/S0)**4+TERM1*(TERM2*H12+ARGP**2*H22)
13     ELSE
14         COFAMN = TERM1*(TERM2*J1+ARGP**2*J2)
15         ARGU = KSO*RHO
16         CALL CBESJY(ARGU,0,BJ,BY,0)
17         H02 = BJ-IM*BY
18         CAPA = COFAMN+H02*CAPG1(RHO)
19     END IF
20     RETURN
21     END

```

# DISTRIBUTION LIST

DEPARTMENT OF DEFENSE  
 ASSISTANT SECRETARY OF DEFENSE  
 CMD, CONT, COMM & INTELL  
 DEPARTMENT OF DEFENSE  
 WASHINGTON, DC 20301

DIRECTOR  
 COMMAND CONTROL TECHNICAL CENTER  
 11440 ISAAC NEWTON SQUARE, N  
 RESTON, VA 22091  
 C-650

DIRECTOR  
 COMMAND CONTROL TECHNICAL CENTER  
 ROOM ME682, THE PENTAGON  
 WASHINGTON, DC 20301  
 C-312

DIRECTOR  
 DEFENSE ADVANCED RESEARCH PROJECT  
 AGENCY  
 1440 WILSON BLVD  
 ARLINGTON, VA 22209  
 NUCLEAR MONITORING RSCH  
 STRATEGIC TECH OFFICE

DEFENSE COMMUNICATION ENGINEERING CENTER  
 1860 WIEHLE AVENUE  
 RESTON, VA 22090  
 CODE R220 (M HOROWITZ)  
 CODE R720 (JOHN WORTHINGTON)  
 CODE R410 (JAMES W MC LEAN)  
 CODE R103

DIRECTOR  
 DEFENSE COMMUNICATIONS AGENCY  
 WASHINGTON, DC 20305  
 CODE 810  
 CODE 480  
 CODE 101B

DEFENSE COMMUNICATIONS AGENCY  
 WWMCCS SYSTEM ENGINEERING ORG  
 WASHINGTON, DC 20305  
 RL CRAWFORD

DEFENSE TECHNICAL INFORMATION CENTER  
 CAMERON STATION  
 ALEXANDRIA, VA 22314

DIRECTOR  
 DEFENSE INTELLIGENCE AGENCY  
 WASHINGTON, DC 20301  
 DIAST-5  
 DB-4C (EDWARD O'FARRELL)

DIRECTOR  
 DEFENSE NUCLEAR AGENCY  
 WASHINGTON, DC 20305  
 DDST  
 TISI ARCHIVES  
 TITL TECH LIBRARY  
 RAAE  
 ST v L

DIRECTOR  
 JOINT STRAT TGT PLANNING STAFF JCS  
 OFFUTT AFB  
 OMAHA, NB 68113  
 JPST

COMMANDER  
 FIELD COMMAND  
 DEFENSE NUCLEAR AGENCY  
 KIRTLAND AFB, NM 87115  
 FCPR

DIRECTOR INTERSERVICE NUCLEAR WEAPONS SCHOOL  
 KIRTLAND AFB, NM 87115  
 DOCUMENT CONTROL

CHIEF  
 LIVERMORE DIVISION FLD COMMAND DNA  
 LAWRENCE LIVERMORE LABORATORY  
 PO BOX 808  
 LIVERMORE, CA 94550  
 FCPR L

DIRECTOR  
 NATIONAL SECURITY AGENCY  
 FT GEORGE G MEADE, MD 20755  
 W65  
 OLIVER H BARTLETT W32  
 TECHNICAL LIBRARY  
 JOHN SKILLMAN R52

OJCS/J-3  
 THE PENTAGON  
 WASHINGTON, DC 20301  
 OPERATIONS (WWMCCS EVAL  
 OFF, MR TOMA)

OJCS/J-5  
 THE PENTAGON  
 WASHINGTON, DC 20301  
 PLANS & POLICY (NUCLEAR DIVISION)

UNDER SECY OF DEFENSE FOR RESEARCH  
 AND ENGINEERING  
 DEPARTMENT OF DEFENSE  
 WASHINGTON, DC 20301  
 S&SS (OS)

DEPARTMENT OF THE ARMY

COMMANDER/DIRECTOR  
ATMOSPHERIC SCIENCES LABORATORY  
US ARMY ELECTRONICS COMMAND  
WHITE SANDS MISSILE RANGE, NM 88002  
DELAS-AE-M (FE NILES)

COMMANDER  
HARRY DIAMOND LABORATORIES  
2800 POWDER MILL RD  
ADELPHI, MD 20783  
DELHD-NP (FN WIMENITZ)  
MILDRED H WEINER DRXDO-II

COMMANDER  
US ARMY ELECTRONICS RESEARCH &  
DEVELOPMENT COMMAND  
FORT MONMOUTH, NJ 07703  
DRSEL-RD  
(JE QUIGLEY)

COMMANDER  
US ARMY FOREIGN SCIENCE & TECH CENTER  
220 7TH STREET, NE  
CHALOTTESVILLE, VA 22901  
R JONES  
PA CROWLEY

COMMANDER  
US ARMY NUCLEAR AGENCY  
7500 BACKLICK ROAD  
BUILDING 2073  
SPRINGFIELD, VA 22150  
MONA-WE (J BERBERET)

CHIEF  
US ARMY RESEARCH OFFICE  
PO BOX 12211  
TRIANGLE PARK, NC 27709  
DRXRD-ZC

DEPARTMENT OF THE NAVY

CHIEF OF NAVAL OPERATIONS  
NAVY DEPARTMENT  
WASHINGTON, DC 20350  
OP 941  
OP-604C3  
OP 943  
OP 981

CHIEF OF NAVAL RESEARCH  
NAVY DEPARTMENT  
ARLINGTON, VA 22217  
CODE 402  
CODE 420  
CODE 421  
CODE 481  
CODE 484

COMMANDING OFFICER  
NAVAL INTELLIGENCE SUPPORT CENTER  
4301 SUITLAND RD BLDG 5  
WASHINGTON, DC 20390

OFFICER-IN-CHARGE  
WHITE OAK LABORATORY  
NAVAL SURFACE WEAPONS CENTER  
SILVER SPRING, MD 20910  
CODE WA501 NAVY NUC PRGMS OFF  
CODE WX21 TECH LIBRARY

COMMANDER  
NAVAL TELECOMMUNICATIONS COMMAND  
NAVTELCOM HEADQUARTERS  
4401 MASSACHUSETTS AVE, NW  
WASHINGTON, DC 20390  
CODE 24C

COMMANDING OFFICER  
NAVY UNDERWATER SOUND LABORATORY  
FORT TRUMBULL  
NEW LONDON, CT 06320  
PETER BANNISTER  
DA MILLER

DIRECTOR  
STRATEGIC SYSTEMS PROJECT OFFICE  
NAVY DEPARTMENT  
WASHINGTON, DC 20376  
NSP-2141

DEPARTMENT OF THE AIR FORCE

COMMANDER  
ADC/DC  
ENT AFB, CO 80912  
DC (MR LONG)

COMMANDER  
ADCOM/XPD  
ENT AFB, CO 80912  
XPDDQ  
XP

AF GEOPHYSICS LABORATORY, AFSC  
HASCOM AFB, MA 01731  
CRU (S HOROWITZ)

AF WEAPONS LABORATORY, AFSC  
KIRTLAND AFB, NM 87117  
SUL (2)  
DYC

COMMANDER  
ROME AIR DEVELOPMENT CENTER, AFSC  
GRIFFISS AFB, NY 13440  
EMTLD DOC LIBRARY

COMMANDER  
ROME AIR DEVELOPMENT CENTER, AFSC  
HANSOM AFB, MA 01731  
EEP JOHN RASMUSSEN

COMMANDER IN CHIEF  
STRATEGIC AIR COMMAND  
OFFUTT AFB, NB 68113  
NRT  
XPFS

LAWRENCE LIVERMORE NATIONAL  
LABORATORY  
PO BOX 808  
LIVERMORE, CA 94550  
TECH INFO DEPT L-3

LOS ALAMOS NATIONAL SCIENTIFIC  
LABORATORY  
PO BOX 1663  
LOS ALAMOS, NM 87545  
DOC CON FOR T F TASCHEK  
DOC CON FOR D R WESTERVELT  
DOC CON FOR P W KEATON

SANDIA LABORATORY  
LIVERMORE NATIONAL LABORATORY  
PO BOX 969  
LIVERMORE, CA 94550  
DOC CON FOR B E MURPHEY  
DOC CON FOR T B COOK ORG 8000

SANDIA NATIONAL LABORATORY  
PO BOX 5800  
ALBUQUERQUE, NM 87115  
DOC CON FOR SPACE PROJ DIV  
DOC CON FOR A D THORNBROUGH  
DOC CON FOR 3141 SANDIA RPT COLL

OTHER GOVERNMENT  
DEPARTMENT OF COMMERCE  
NATIONAL BUREAU OF STANDARDS  
WASHINGTON, DC 20234  
RAYMOND T MOORE

DEPARTMENT OF COMMERCE  
OFFICE OF TELECOMMUNICATIONS  
INSTITUTE FOR TELECOM SCIENCE  
BOULDER, CO 80302  
WILLIAM F UTLAUT  
L A BERRY  
A GLENN JEAN

DEPARTMENT OF DEFENSE CONTRACTORS  
AEROSPACE CORPORATION  
PO BOX 92957  
LOS ANGELES, CA 90009  
IRVING M GARFUNKEL

ANALYTICAL SYSTEMS ENGINEERING CORP  
5 OLD CONCORD RD  
BURLINGTON, MA 01803  
RADIO SCIENCES

THE BOEING COMPANY  
PO BOX 3707  
SEATTLE, WA 98124  
GLEEN A HALL  
J F KENNEY

ESL, INC  
495 JAVA DRIVE  
SUNNYVALE, CA 94086  
JAMES MARSHALL

GENERAL ELECTRIC COMPANY  
SPACE DIVISION  
VALLEY FORGE SPACE CENTER  
GODDARD BLVD KING OF PRUSSIA  
PO BOX 8555  
PHILADELPHIA, PA 19101  
SPACE SCIENCE LAB (MH BORTNER)

KAMAN TEMPO  
816 STATE STREET  
PO DRAWER QQ  
SANTA BARBARA, CA 93102  
B GAMBILL  
DASIAC  
WARREN S KNAPP

GTE SYLVANIA, INC  
ELECTRONICS SYSTEMS GRP  
EASTERN DIVISION  
77 A STREET  
NEEDHAM, MA 02194  
MARSHAL CROSS

IIT RESEARCH INSTITUTE  
10 WEST 35TH STREET  
CHICAGO, IL 60616  
TECHNICAL LIBRARY

UNIVERSITY OF ILLINOIS  
DEPARTMENT OF ELECTRICAL ENGINEERING  
URBANA, IL 61803  
AERONOMY LABORATORY

JOHNS HOPKINS UNIVERSITY  
APPLIED PHYSICS LABORATORY  
JOHNS HOPKINS ROAD  
LAUREL, MD 20810  
J NEWLAND  
PT KOMISKE

LOCKHEED MISSILES & SPACE CO, INC.  
3251 HANOVER STREET  
PALO ALTO, CA 94304  
E E GAINES  
W L IMHOF D/52-12  
J B REAGAN D652-12  
R G JOHNSON D/52-12

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
LINCOLN LABORATORY  
PO BOX 73  
LEXINGTON, MA 02173  
D M TOWLE

MISSION RESEARCH CORPORATION  
735 STATE STREET  
SANTA BARBARA, CA 93101  
R HENDRICK  
F FAJEN

MITRE CORPORATION  
PO BOX 209  
BEDFORD, MA 01730  
G HARDING

PACIFIC-SIERRA RESEARCH CORP  
1456 CLOVERFIELD BLVD  
SANTA MONICA, CA 90404  
E C FIELD, JR

PENNSYLVANIA STATE UNIVERSITY  
IONOSPHERIC RESEARCH LABORATORY  
318 ELECTRICAL ENGINEERING EAST  
UNIVERSITY PARK, PA 16802  
IONOSPHERIC RSCH LAB

R&D ASSOCIATES  
PO BOX 9695  
MARINA DEL REY, CA 90291  
FORREST GILMORE  
WILLIAM J KARZAS  
PHYLLIS GREIFINGER  
CARL GREIFINGER  
H A ORY  
BRYAN GABBARD  
R P TURCO  
SAUL ALTSCHULER

RAND CORPORATION  
1700 MAIN STREET  
SANTA MONICA, CA 90406  
TECHNIAL LIBRARY  
CULLEN CRAIN

SRI INTERNATIONAL  
333 RAVENSWOOD AVENUE  
MENLO PARK, CA 94025  
DONALD NEILSON  
GEORGE CARPENTER  
W G CHETNUT  
J R PETERSON  
GARY PRICE

STANFORD UNIVERSITY  
RADIO SCIENCE LABORATORY  
STANFORD, CA 94305  
R A HELLIWELL  
FRASER SMITH  
J KATSUFRAKIS

CALIFORNIA INSTITUTE OF TECHNOLOGY  
JET PROPULSION LABORATORY  
4800 OAK GROVE DRIVE  
PASADENA, CA 91103  
ERNEST K SMITH

ATE  
LMED  
-8